Neurotoxicology 108 (2025) 1–10

Contents lists available at ScienceDirect

Neurotoxicology

journal homepage: www.elsevier.com/locate/neuro

World Trade Center response activities and cognitive health: A moderated mediation study of the role of surgical/nuisance dust mask usage☆

Yuan Yang [a], Jaymie Meliker [a], Lauren L. Richmond [b], Frank D. Mann [a], Minos Kritikos [a], Dylan M. Smith [a], Tesleem Babalola [a], Melissa A. Carr [c], Benjamin J. Luft [c], Sean A.P. Clouston [a,*]

[a] Program in Public Health and Department of Family, Population, and Preventive Medicine, Renaissance School of Medicine at Stony Brook University, USA
[b] Department of Psychology, Stony Brook University, Stony Brook, NY 11794, USA
[c] World Trade Center Health and Wellness Program, Stony Brook University (SUNY), Stony Brook, NY, USA

ARTICLE INFO

Keywords:
World Trade Center
Cognitive impairment
Surgical mask
Nuisance dust mask
Occupational exposure
Disaster response

ABSTRACT

Objective: This study explores the relationship between World Trade Center (WTC) response activities (WRAs) and cognitive impairment (CI) and uses a moderated-mediation model to examine the role of wearing a surgical/nuisance dust mask.

Methods: This study includes 3285 WTC responders. Responders were placed into eight WRA groups based on self-report structured responses and free-text descriptions of activities at the WTC. The presence/absence of surgical/nuisance dust mask usage was self-reported. The outcome was CI as determined using a Montreal Cognitive Assessment score < 23. Robust Poisson regression was used to examine the main effect, and counterfactual moderated-mediation analysis was used to determine the role of mask usage.

Results: The risk of CI was higher across most WRAs when compared to supervision. Mask usage was reported by 63 % of responders and varied across WRAs and was associated with a reduced risk of CI (adjusted risk ratio [aRR]=0.77, p = 0.008) after controlling for WRAs. Moderation effects indicated that responders are more likely to wear masks when encountering more dangerous exposures, even within the same WRA group. Responders in the WRA-enclosed group had a lower risk of CI through a moderated intermediary effect of mask usage (aRR=0.92, p = 0.05).

Conclusion: Surgical/nuisance dust mask usage provided mild protection against air pollution exposures during WTC response activities when compared to not wearing a mask. Results suggest that response workers at disaster sites might benefit from wearing surgical/nuisance dust masks when respirators are unavailable even when the air seems safe.

1. Introduction

An estimated 152 million people will have dementia by 2050, up from 57 million in 2019 (Nichols et al., 2022). Dementia, marked by severe cognitive impairment (CI) that disrupts daily life (Duong et al., 2017), leads to healthcare costs that are 60 % higher than for cancer or heart disease (Kelley et al., 2015; Wong, 2020). Thus, targeted interventions should focus on high-risk populations. After 9/11, over 91,000 responders faced psychological stress and air pollutants (Smith et al., 2021). As a result, dementia incidence among WTC responders (14.47 /1000 person-years, mean age = 52) exceeds that in the general population, with higher rates among severely exposed responders without protective equipment (Clouston et al., 2024).

WTC settled dust, comprising particulate matter (PM) and neurotoxic chemicals including dioxins, and polycyclic aromatic hydrocarbons (Kritikos et al., 2020), might impact cognition via translocation into the brain via the olfactory bulb or by immune activation (Clouston et al., 2022). In situations with low air movement, WTC dust was resuspended in 75 % of locations, with 2 % being PM<10μm in size (Lippmann et al., 2015). Different WTC response activities (WRAs) exposed responders to various neurotoxins: steel workers were exposed to neurotoxic metals (Li et al., 2004), responders in enclosed environment were exposed to

☆ Institution at which the work was performed: Stony Brook University

* Correspondence to: Program in Public Health, Health Sciences Center, #3-071, 101 Nichols Rd., Stony Brook, NY 11794-8338, USA.
E-mail address: Sean.clouston@stonybrookmedicine.edu (S.A.P. Clouston).

https://doi.org/10.1016/j.neuro.2025.02.002
Received 30 September 2024; Received in revised form 4 February 2025; Accepted 11 February 2025
Available online 15 February 2025

carbon monoxide (Rajakumar and Choi, 2023), heavy equipment operators faced WTC dust and exhaust fumes (Stern and Haring-Sweeney, 1997), utility/maintenance workers were exposed to organic solvents (Hakim and Moamen, 2018; Sainio, 2015). Research has clarified that the duration of WTC exposure is related to cognitive dysfunction in responders (Clouston et al., 2017) and survivors of the tower collapse (Rosen et al., 2022). However, these studies have not captured variability in CI risk due to different WRAs. Understanding how specific WRAs contribute to CI is needed for targeted prevention in future response activity.

Most responders lacked access to respirators, and those who had them often used them incorrectly or inconsistently (Centers for Disease Control and Prevention CDC, 2002; Nash, 2002). Multiple reports have indicated that the restrictive nature of respirators partly contributed to their limited use during search and rescue operations in the rubble. Thus, most responders opted to forgot wearing any mask or to rely exclusively on a surgical/nuisance dust mask. Surgical masks have been reported to have limited efficacy against small particles when compared to respirators, but studies also suggest that surgical masks are protective against some forms of air pollution, especially when compared to not wearing a mask (Duncan et al., 2021; Kodros et al., 2021). To date, little is known about the long-term implications of the decision to wear a dust mask on neurological health in responders.

A significant gap remains in understanding how WRA influences mask-wearing, and the impact of those choices on cognitive health (Reissman and Howard, 2008). To date, no study of WTC responders has examined the benefits of wearing a surgical/nuisance dust when compared to not wearing mask. This study aimed to 1) examine how WRAs affect CI and 2) assess whether variable surgical/nuisance dust mask usage played an intermediary variable or moderating role linking WRAs with the risk of CI. We hypothesized that WRAs that have higher potential for air pollution exposures would be associated with increased risk of CI, and that surgical/nuisance dust masks significantly intermediate and moderate the association between WRAs and CI. To our knowledge, this is the first study to build WRA variables and the first to examine the intermediator/moderator role of surgical/nuisance dust masks on cognitive health.

2. Methods

2.1. Population

All responders who were involved in the response efforts following the 9/11 attacks were eligible to participate in the parent WTC monitoring program (Dasaro et al., 2017). A nested cohort from the Stony Brook University clinical center was established to evaluate cognition in consenting WTC responders who began attending cognitive monitoring appointments in November 2014. This cohort had comparable exposures and ages with the general responder group but was mostly comprised of law enforcement professionals, males, and high school graduates (Clouston et al., 2016). On average, responders completed their initial exposure measurement by June 2012 and their cognitive assessment by July 2017. The exclusion criteria for the present study are outlined in Fig. 1. Participants were excluded from the analysis if they did not respond during the first week. As noted above, because of reports that many responders who had respirators did not use them correctly or regularly, we excluded those who reported using respirators other than surgical/nuisance dust masks (e.g., half-face and full-face respirators).

2.2. WTC response activity (WRA)

The response efforts were lengthy and complicated, so WRAs were captured using several variables. In each one of four response periods (September 2001, October 2001, November-December 2001, and January-June 2002), responders were asked to provide responses to codes for up to 55 distinct response activities including activities such as canteen services, cable installation, escorting, firefighting, perimeter security, and search and rescue, among others. In addition, responders were asked whether in each period they supervised others during this work, whether they worked in an enclosed environment, and whether they worked in steel work (e.g., torching, cutting, burning). Next, responders were asked to describe their primary activity during each response period in a free text format. Data from free text sometimes differs from structured responses so, from this information, we began by establishing WRA categories to capture response activities

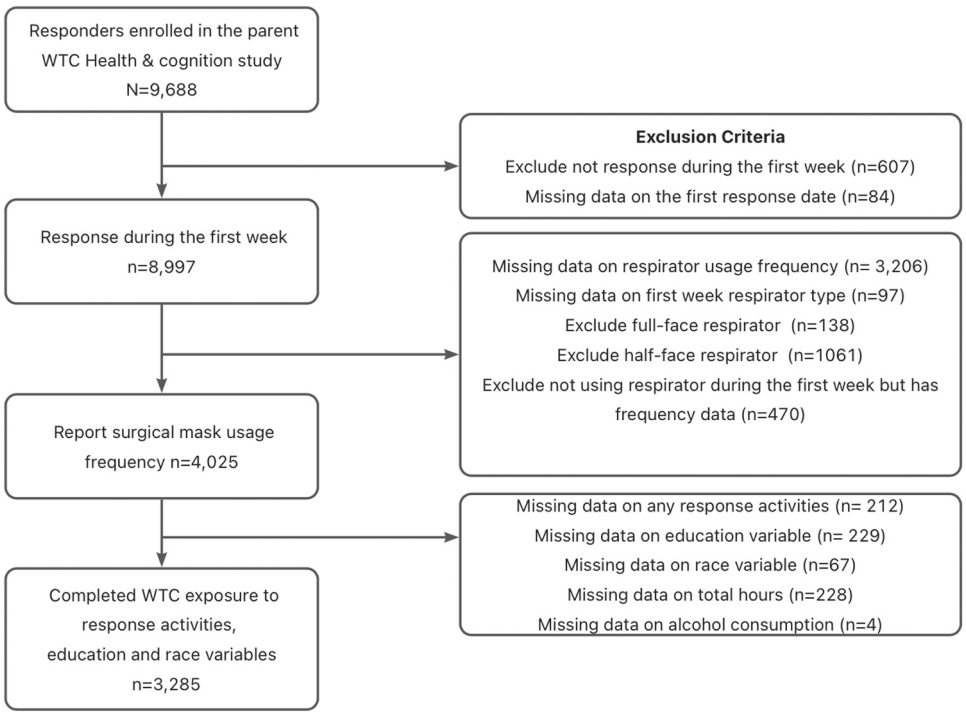

Fig. 1. Recruitment Flow Chart World Trade Center Analytic Sample.

(Supplemental Table **I**). We extracted WRA group information from free text data using natural language processing (NLP, Fig. 2). The NLP pipeline retrieved both responders' activity descriptions and eighteen distinct WRA label descriptions by initially removing stop words, numbers, and rare words (occurring <10 times across all participants). The cleaned text data were converted into numerical vectors to calculate similarities, allowing us to assign activities to each word based on estimated textual similarity. Following a manual review, we followed guidance from Harber and Leroy (2017) and created an activity dictionary to help us assign responders to any combination of eighteen distinct WRAs (Supplemental Table I).Fifty-five occupational code were reclassified into 18 distinct WRAs (Supplemental Table **II**).

Many responders participated in multiple activities at the WTC site, so we assigned multiple activities to each responder across time. The final WRA*time variables merged results from NLP based on free-text descriptions and structured occupational codes/measures describing overlapping categories of work-related variables such as steel work, enclosed environment, and supervision. Specifically, if any variables indicated that the responders did a specific WRA then we rated them as having done that WRA. This process resulted in seventy-two (18*4 time) WRA*time variables that were often overlapping and were also clustered together. For example, individuals who completed search activities often also reported working in rescue and recovery work because while these are independent activities they are complementary.

To simplify WRA categories for analysis, we next classified work-related activity (WRA) categories into mutually exclusive groups based on their occupations coupled with their perceived levels of risk. First, a search and rescue group was characterized by activities conducted near the debris pile, with or without a security component, and was presumed to have significantly higher dust exposure. Second, a supervision group was created that we used as the reference group because we felt that responders involved in supervision are often more involved in oversight and less likely to be involved in manually searching through or moving debris, which would likely result in the lowest risk of cognitive impairment. Third, a security group consisted exclusively of individuals conducting security tasks, typically performed at the perimeter of the WTC site, and thought to have lower WTC dust though having significant exposure to exhaust fumes. Fourth, we created an enclosed group that we felt would have less exposure when combined with repair tasks that were typically performed outside the primary WTC sites. Fifth, we created a similar group of morgue workers who we felt would have relatively high levels of mask usage due to occupational standards and concerns about infectious disease but would also have relatively low risk because individuals worked in clean rooms that were not exposed to ambient WTC air pollution though being exposed to some dust via their work with dusty body parts found at the site. Sixth, we created a group of cable and other utility workers who may have completed repairs outside of enclosed spaces. Seventh, we defined support work as having completed work ferrying items and tools to or from the sites without significant exposure to on-site debris removal or search and rescue activities. Finally, we created a debris-removal-steel group that was defined as involving debris removal, transportation, or heavy equipment operation that we felt might have exposed workers to high levels of WTC dust and ambient air pollution.

2.3. Surgical/nuisance dust mask usage

Data on mask use was obtained through self-reported surveys administered at study enrollment. Surgical/nuisance dust mask use is determined by two variables: the type of mask used during the first exposure week (surgical/nuisance dust masks, and none), and the frequency of mask use over entire periods (rarely, sometimes, most of the time, and always). The surgical/nuisance dust mask usage variable in this study was recategorized into the binary variable with values of no (none and rarely used, the reference group) and yes (surgical/nuisance dust mask usage at least sometimes).

2.4. Reasons for not wearing masks or respirators

For descriptive purposes, we report reasons that responders reported not wearing masks or respirators that were obtained at the same time using three questions for each response period: *When you didn't wear respirator, it was because: I did not wear a respirator at all during [period] because… (detailed reason for not having); I did not wear respirator at all during [period] because… (detailed reason for having but not wearing)*. The first and last questions share the same values, while the second has three values: *I didn't ask for one, None available, or I asked for one but no one would give me one*. Each participant was asked three questions about reasons for not wearing masks or respirators across the response period. To describe mask usage reasoning, we identified and reported all unique responses.

2.5. Cognitive impairment

Cognition (2014–2022) was assessed by the Montreal Cognitive Assessment (MoCA), a concise cognitive screening instrument known for its high sensitivity and specificity in the screening of CI (Nasreddine et al., 2005). The MoCA is used to detect the presence of CI and works by evaluating several cognitive domains, including memory, attention, language, visuospatial and executive functions, and orientation (Cersonsky et al., 2022). Memory is assessed through a five-word delayed recall task, while attention is evaluated using digit span tests, vigilance tasks, and serial subtraction. Language assessment includes naming, sentence repetition, and fluency tasks. Visuospatial and executive functions are tested with clock drawing, cube copying, and sequence alternation tasks. Finally, Orientation is measured by asking participants about the current date, location, and other contextual details (Cersonsky et al., 2022). Scores were combined using the standard algorithm and following prior epidemiological work. We operationalized CI using a relatively conservative cutoff score of < 23, consistent with mild cognitive impairment (Luis et al., 2009).

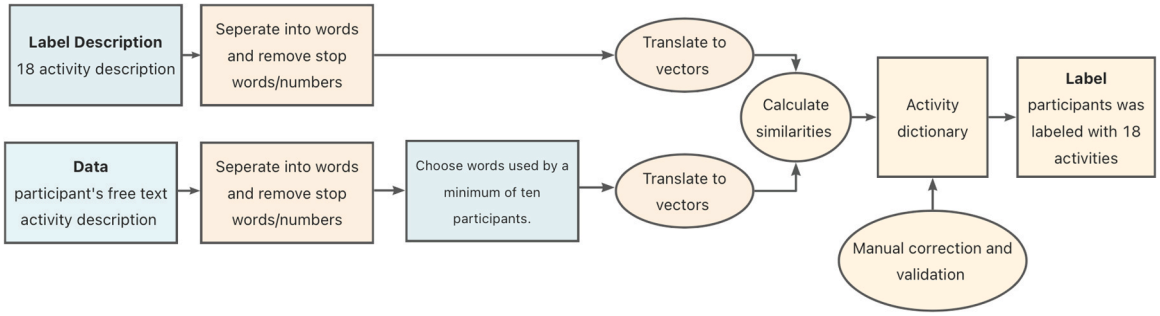

Fig. 2. The Data Pipeline Linking Natural Language Processing to Structured Activity Data to Generate Response Activity Groups.

2.6. Covariates

Demographic factors included responder age (in years) when they completed the MoCA, biological sex, educational achievement (≤High School and ≤ Bachelor of Science), and race (White, Non-white). Total working hours were scaled using the interquartile range. Smoking and alcohol use were time-varying variables, and values at the time of cognitive assessment were used in the analyses. Smoking was classified as a non-smoker, past smoker, and current smoker, whereas alcohol use was classified as a non-drinker, less than one drink per week, and more than one drink per week.

2.7. Statistical analysis

The analysis started by describing the sample characteristics in terms of demographics and other covariates using means and interquartile ranges (25th percentile, 75th percentile) or frequencies and percentages (%). A frequency plot was provided to illustrate the reasons for not wearing masks. We assessed the main effects of WRA and mask usage on CI using Robust Poisson regressions (Chen et al., 2018).

Since robust Poisson models may be biased under some circumstances and do not fully elucidate the potential factors related to mask usage, we employed a counterfactual method to examine the potential intermediary effects of variability in mask usage across WRAs that may be perceived by responders themselves as varying in levels of overall exposure risk. Specifically, we used a moderated mediation model that leverages the probability of conditions that would occur under different hypothetical scenarios to estimate the "Total Effect (TE) into "Natural Indirect Effect (NIE)" and "Natural Direct Effect (NDE)" (Valeri and Vanderweele, 2013). The NIE is CI risk ratio under two scenarios: a) individuals are exposed to WRA and mask usage is set to the level it would be if they were not exposed; b) individuals are exposed to WRA and mask usage is set to the level it would be if they were exposed (Valeri and Vanderweele, 2013). This method is preferred for handling common binary outcomes and effectively addressing interactions between exposure and intermediator, offering advantages over traditional methods like the product approach (Caubet. et al., 2023; Valeri and Vanderweele, 2013). When properly specified, the NIE captures the risk change when the intermediate variable mask changes from it would be under unexposed to exposed WRA while individuals are fixed to the exposed WRA condition. Similarly, the NDE examined how risk changed given the pure change of exposure condition with mask usage fixed to the level it would be under no exposure. However, while moderated mediation models are employed, because mask usage is not conceptualized as a traditional mediator of the relationship between WRAs and the risk of CI, we use the term "intermediary" throughout this manuscript.

The interaction term-WRA*mask was added to the outcome regressions to adjust for effect modification. All moderated-mediation analyses additionally adjusted for age, sex/gender, education, race/ethnicity, working hours, smoking, and alcohol use for both the mediator and outcome regressions.

To facilitate the understanding of intermediary results and how WRA impacts mask usage, we also did a Robust Poisson Regression of WRA to examine the risk of mask usage. The same set of covariates were adjusted, and multiple comparisons were controlled by False Discovery Rate (FDR). To further examine the mask protective role within each specific WRA group, we used robust Poisson regression of mask usage on CI stratified by WRA. Covariates and multiple comparisons were adjusted in the model.

3. Results

After application of inclusion/exclusion criteria, a total of 3285 individuals were included in this study (Fig. 1). Responders who were included in the study tended to be younger (Hedge's $g = -0.16$), worked longer (Hedge's $g = 0.10$), and were less likely to have CI (14.3 % vs. 17.5 %) compared to those excluded from this study (Supplemental Table **III**).

Responders in the analytic sample (Table 1) were in their fifties at the time of cognitive assessment, and the majority were male (Male=91.3 %). Those who did not wear surgical/nuisance dust masks tended to have shorter working hours (Hedge's $g = -0.33$), and higher rates of CI (17.4 % vs. 12.5 %). They also had lower education attainment than those who reported wearing a surgical/nuisance dust mask (Table 1).

Since many responders report not wearing any masks, we described the reasons that responders provided for not wearing a mask(Fig. 3A), the prevalence of CI and surgical mask use across WRAs (Fig. 3B). While a lack of availability was the most cited reason across the entire cohort, discomfort was the most frequent reason in this analysis sample. Responders' perceptions of environmental risk were also given as one reason that individuals chose not to wear a mask.

In Table 2, we outlined the percentage of mask usage among eight mutually exclusive WRA groups and examined the multivariable-

Table 1
Baseline Characteristics of the World Trade Center Responders.

Characteristic	N	Overall N = 3285[a]	No surgical/ nuisance dust mask usage N = 1221[a]	Wore a surgical/ nuisance dust mask N = 2064[a]	p-value[b]
Age	3285	51.99 (47.10, 57.26)	52.81 (47.48, 58.84)	51.71 (46.84, 56.63)	< 0.001
Biological Sex	3285				< 0.001
Male		2999 (91.3 %)	1084 (88.8 %)	1915 (92.8 %)	
Female		286 (8.7 %)	137 (11.2 %)	149 (7.2 %)	
Race	3285				0.002
Non-White		380 (11.6 %)	114 (9.34 %)	266 (12.9 %)	
White		2905 (88.4 %)	1107 (90.7 %)	1798 (87.1 %)	
Education	3285				0.026
≤ Bachelor of Science		2607 (79.4 %)	944 (77.3 %)	1663 (80.6 %)	
≤High School		678 (20.6 %)	277 (22.7 %)	401 (19.4 %)	
Smoking	3285				0.700
Current		211 (6.4 %)	83 (6.8 %)	128 (6.2 %)	
Never		2087 (63.5 %)	766 (62.7 %)	1321 (64.0 %)	
Former		987 (30.0 %)	372 (30.5 %)	615 (29.8 %)	
Alcohol Consumption	3285				< 0.001
None/non drinker		688 (20.9 %)	298 (24.4 %)	390 (18.9 %)	
Less than one drink per week		1479 (45.0 %)	518 (42.4 %)	961 (46.6 %)	
More than one drink per week		1118 (34.0 %)	405 (33.2 %)	713 (34.5 %)	
Total Working Hours (scaled by IQR)	3285	0.54 (0.20, 1.22)	0.30 (0.07, 0.97)	0.65 (0.32, 1.33)	< 0.001
Cognition Diagnosis	3285				< 0.001
Cognitively Unimpaired		2815 (85.7 %)	1008 (82.6 %)	1807 (87.5 %)	
Cognitively Impaired		470 (14.3 %)	213 (17.4 %)	257 (12.5 %)	

[a] Median (Q1, Q3); n (%)
[b] Wilcoxon rank sum test; Pearson's Chi-squared test

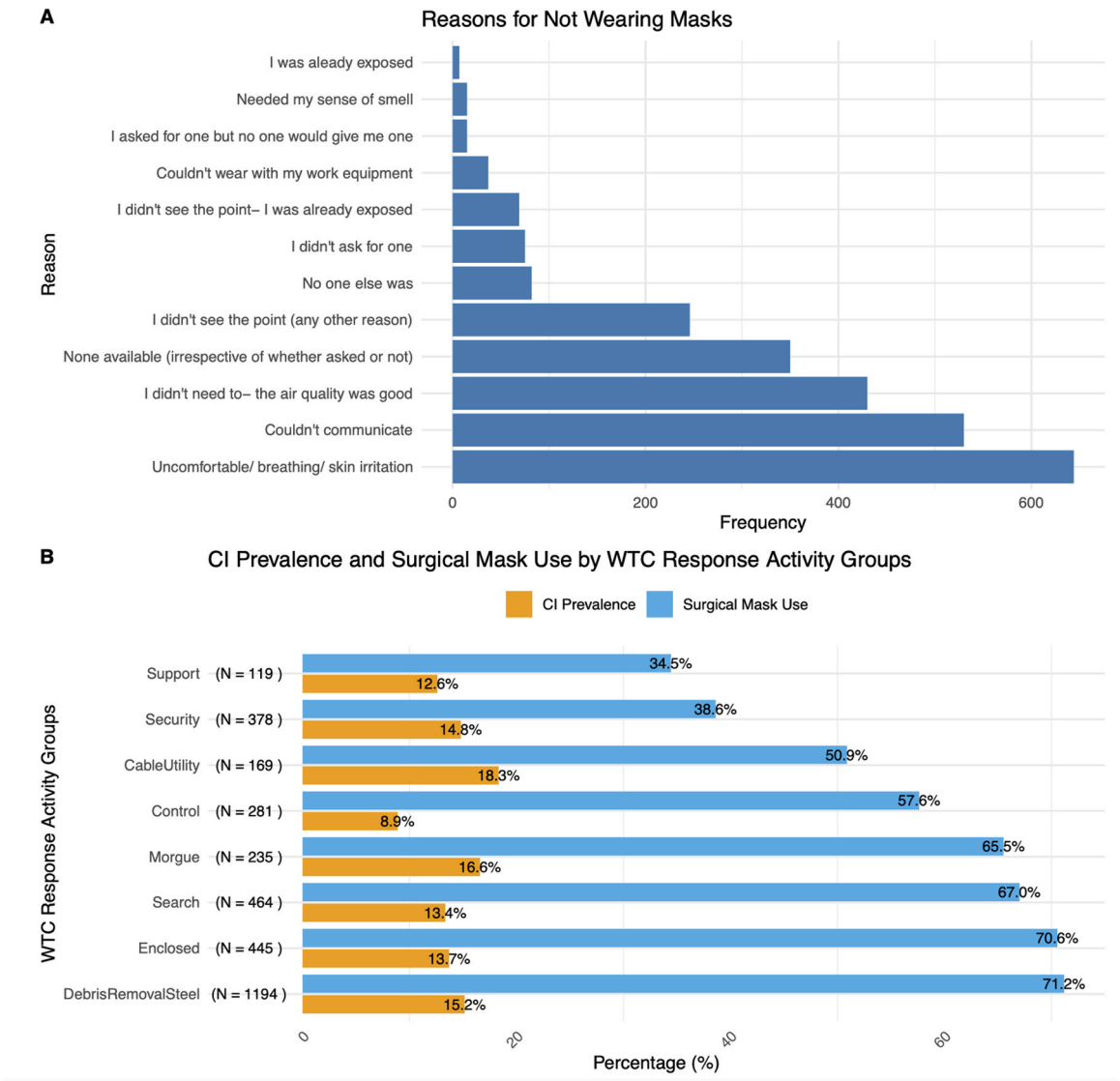

Fig. 3. Reasons for Not Wearing Masks as well as the prevalence of Mask Usage, and Cognitive Impairment within Each World Trade Center Response Activity Group.

Table 2
Robust Poisson Regression of World Trade Center Response Activity (WRA) as a Covariable to explain variation in Mask Usage.

Predictor	N	Prevalence of Mask Use (%)	aRR	Lower	Upper	P adjusted
Supervision (reference)	281	57.65	1.00			
Cable Utility	169	50.89	0.90	0.75	1.07	0.270
Debris Removal Steel	**1194**	**71.19**	**1.22**	**1.10**	**1.36**	**< 0.001**
Enclosed	**445**	**70.56**	**1.19**	**1.06**	**1.33**	**0.008**
Morgue	235	65.53	1.11	0.97	1.27	0.165
Search	**464**	**67.03**	**1.16**	**1.03**	**1.30**	**0.020**
Security	**378**	**38.62**	**0.66**	**0.56**	**0.77**	**< 0.001**
Support	**119**	**34.45**	**0.63**	**0.49**	**0.82**	**0.002**

Note: The Poisson model adjusts for age, gender, education, smoking, alcohol consumption, and total hours. **N**: number of observations within each WRA. Prevalence of Mask Use (%): percent of mask usage within each WRA. **aRR**: multivariable-adjusted Rate Ratio; **Lower**: lower boundary of 95 % Confidence Interval; **Upper**: upper boundary of 95 % Confidence Interval; **P adjusted**: False Discovery Rate (FDR) adjusted p-value.

adjusted risk of mask usage within each group and reported the risk ratio when compared to supervisorial work. Overall, Table 2 revealed significant associations between WRAs and mask-wearing behavior. Though not shown in Table 2, most responders (65 %) reported consistent WRA groups throughout the response efforts while some responders changed to debris-removal-steel (16 %), to enclosed (6 %), and search (6 %).

Next, we examined associations between WRA, mask usage, and risk of CI (Table 3) and found that after adjusting for variation in risk due to WRAs, mask usage was associated with a 23 % reduced risk of CI. We also found that most WRA, except for support, were associated with higher risk of CI when compared to supervision work even after adjusting for educational attainment.

Next, we examined the multivariable-adjusted risk of CI among individuals who wore masks as compared to those who did not, stratified by WRA group (Table 4). Overall, stratified results trended in the protective direction in all but one group and demonstrated a statistically significant association between WRA and the risk of CI in enclosed and morgue workers.

Counterfactual models examining the intermediary-moderation studies are shown in Fig. 4. These results illustrated that, when compared to the supervision group, participation in most WRAs (except for support work) had significantly higher NDE and TE estimates,

Table 3
Results from Robust Poisson Regression for Cognitive Impairment Risk including World Trade Center Response Activity and Mask Usage as Covariables.

Predictor	Prevalence of CI (%)	aRR	Lower	Upper	P adjusted
Surgical/Nuisance Dust Mask		**0.77**	**0.65**	**0.91**	**0.008**
World Trade Center Response Activity					
Supervision (reference)	8.90	1.00			
Cable Utility	**18.34**	**1.67**	**1.03**	**2.70**	**0.057**
Debris Removal Steel	**15.16**	**1.68**	**1.14**	**2.48**	**0.017**
Enclosed	**13.71**	**1.63**	**1.06**	**2.49**	**0.041**
Morgue	**16.60**	**1.95**	**1.22**	**3.10**	**0.013**
Search	**13.36**	**1.80**	**1.17**	**2.77**	**0.016**
Security	**14.81**	**1.99**	**1.29**	**3.09**	**0.007**
Support	12.61	1.20	0.66	2.18	0.616

Note: The model is adjusted for age, gender, education, smoking, alcohol consumption, and total hours. Prevalence of CI (%): percent of CI within each WRA group. **aRR**: multivariable-adjusted Rate Ratio; **Lower**: lower boundary of 95 % Confidence Interval; **Upper**: upper boundary of 95 % Confidence Interval; **P adjusted**: False Discovery Rate (FDR) adjusted p-value.

Table 4
Robust Poisson Regression examining the association between Mask Usage and the risk of Cognitive Impairment, Stratified by World Trade Center Response Activity.

Strata	aRR	Lower	Upper	P adjusted
Supervision	0.44	0.21	0.93	0.086
Cable Utility	1.40	0.74	2.63	0.477
Debris Removal Steel	0.97	0.73	1.28	0.814
Enclosed	**0.51**	**0.32**	**0.81**	**0.018**
Morgue	**0.43**	**0.25**	**0.76**	**0.018**
Search	0.85	0.54	1.36	0.671
Security	0.90	0.54	1.50	0.784
Support	0.49	0.14	1.71	0.477

Note: In all WRA groups, the risk ratio shows the relative risk of cognitive impairment among mask users as compared to mask non-users. The Model is adjusted for age, gender, education, smoking, alcohol consumption, and total hours. **aRR**: multivariable-adjusted Rate Ratio; **Lower**: lower boundary of 95 % Confidence Interval; **Upper**: upper boundary of 95 % Confidence Interval; **P adjusted**: False Discovery Rate (FDR) adjusted p-value. The **Model** column indicates whether the observations belong to the group of individuals who used masks or those who did not.

consistent with results shown in Table 3. As evidenced by the step-down in NDE over the time-periods, color-sorted results indicate that the NDE of WRA appeared more severe in September, 2001 (yellow) and October, 2001 (blue) when compared to November-December, 2001 (green) or January-June 2002 (violet) time periods. Interestingly, some WRAs like Support and Security showed sizable decreases in NDE and TE over the observed period while other activities including search and rescue, morgue, debris removal, or utility work, though having different overall levels of risk showed little step-down in risk over time.

Table 5 illustrated how variability in mask usage might be an intermediary variable in the relationship between WRAs and CI both with or without inclusion of a moderation effect of the mask (including interaction term in the model). Generally, results from moderated intermediary analyses showed results that were not statistically significant other than in the case of repair work in enclosed spaces. However, when the interaction term was excluded from the model, NIE estimates showed that surgical/nuisance dust mask was associated with protective intermediary effects.

4. Discussion

The goal of this study was to examine how CI risk varies by WRA groupings and whether mask usage differences influence this risk. Using a novel approach to supplement data from structured survey methods with free text descriptions using NLP, the present study found that WRA groups were differentially associated with the risk of CI. Our findings indicated that CI was elevated among individuals involved in all WRA groups except for the support group when compared to the supervision group. Critically, mask usage emerged as a protective factor after adjusting for all WRA groups suggesting that these masks may have helped to mitigate the risk of ambient air exposures affecting many responders who opted to forgo wearing respirators during response activities.

Valeri and Vanderweele (2013) emphasized that interaction terms should always be included in the model for the intermediary analysis, even if they are not statistically significant, as significant interactions can be difficult to detect (Valeri and Vanderweele, 2013). Our "intermediary" results showed notable changes in estimates after controlling for the interaction term that themselves identified no moderating effects of mask usage. The differences may be due to strong associations between WRA and mask usage suggesting that individuals were more likely to wear masks when engaging in more hazardous exposure, a result that responders reported themselves. We also found that WRA-enclosed was associated with intermediary effects of mask usage, instead, suggesting that there was a generalized issue of bias by indication in this study that was resolved by counterfactual models.

Our study contributes new evidence for the intermediary and moderation effects of surgical/nuisance dust mask usage on WTC exposure related CI risk and specifically notes that masks played a protective role in reducing some of the risk of WTC exposure attributed to response activities. Clinical trials have previously demonstrated that surgical/nuisance dust masks are comparably effective to N95 respirators in preventing the transmission of the COVID-19 virus (Radonovich et al., 2019). Notably, the experiments by Radonovich et al. (2019) lacked a control group, limiting the ability to interpret the comparable effectiveness of surgical mask and respirators. Besides, a study by MacIntyre et al. (2013) found that respirators were superior to surgical/nuisance dust masks in limiting respiratory disease in healthcare workers (MacIntyre et al., 2013). The high inward leakage values for surgical/nuisance dust masks reflect their restricted protective capability despite high filtration efficiency (Duncan et al., 2021). Indeed, based on a model simulations study, surgical/nuisance dust masks are less effective than N95 respirators in reducing hospitalizations caused by wildfire smoke exposure, with a reduction of 9–24 % for surgical/-nuisance dust masks compared to 22–39 % for N95 masks (Kodros et al., 2021). While our results specifically excluded respirators and cannot therefore compare results across groups, our results imply that wearing surgical/nuisance dust mask was preferable to not wearing mask with regards to the risk of CI in this group.

These results support prior work considering the linkage between occupational activities and neurological exposures. For example, we find that WRA-security and debris-removal-steel were associated with increased CI, possibly due to the exposure to combustion byproducts (Stern and Haring-Sweeney, 1997). Similarly, our results are also consistent with prior findings that supervisors have the lowest CI risk; the supervision role has been identified as a protective factor against neuropathology among responders (Kritikos et al., 2023). Indeed, a wealth of literature suggests that social inequalities in health may emerge in cognitive impairment in part because individuals with higher access to resources are more likely to avoid both neurologically damaging exposures to modifiable risk factors for dementia (Livingston et al., 2024).

This is the first study to examine the moderated intermediating role of surgical mask usage in preventing air pollution exposure related to CI. Participation in WRAs that were perceived as hazardous in polluted places, like working in an enclosed environment, or in a morgue where mask usage is common because of infectious disease risks was correlated with increased frequency of surgical/nuisance dust mask usage. However, because responders were also more likely to wear masks during

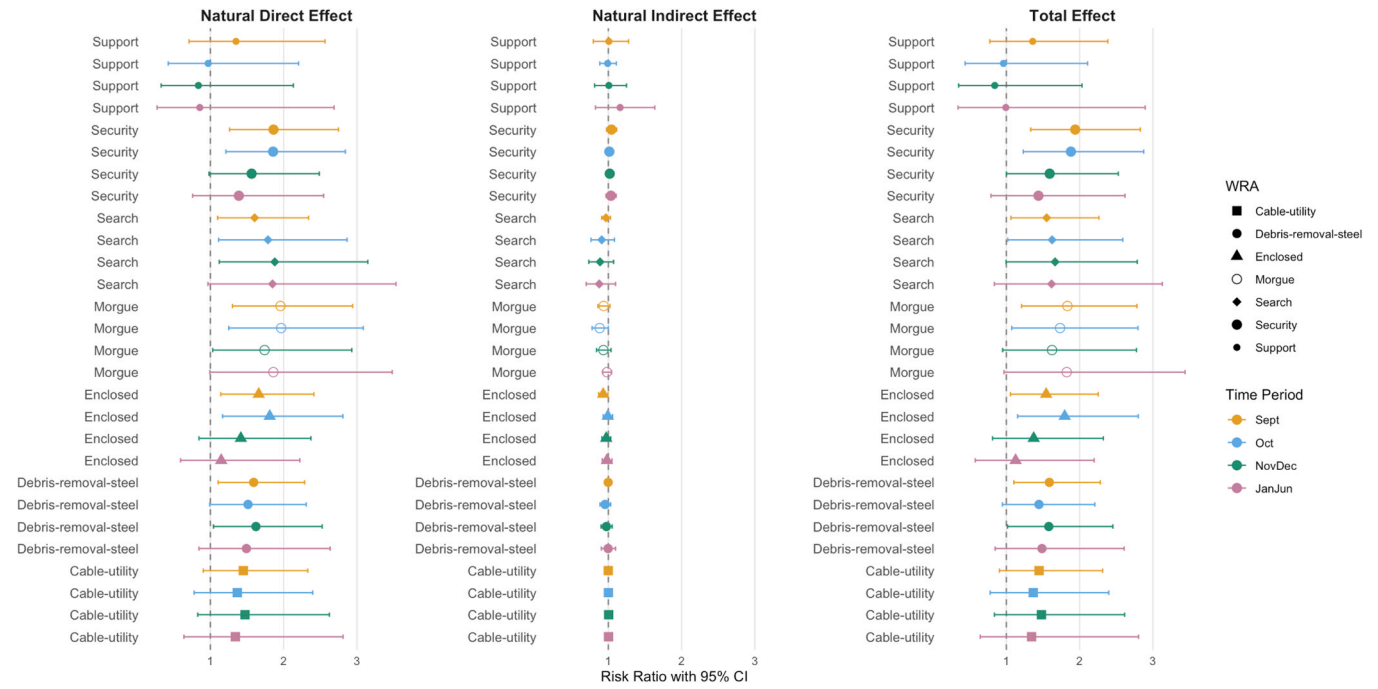

Fig. 4. Risk Ratios showing the association between World Trade Center Response Activity (WRA) on Cognitive Impairment Across Time Periods. Results are Stratified to Clarify Natural Direct, Natural Indirect, and Total Effects. Note that the supervisor group was the reference category and was excluded from the figure.

higher levels of hazardous exposure within the same WRA, most intermediating effects were diminished. Only WRA-enclosed reached significant NIE, which was enhanced by the modifying role of mask use where wearing the mask can significantly mitigate the RR of WRA-enclosed on CI. This also indicated the limited protection surgical/nuisance dust masks can provide and the variability of their protective effects across different WRAs.

The security group, typically involving perimeter security and traffic control at a distance from the pile, is perceived as a safer activity by responders as reflected by their low risk of mask usage. However, our results showed that security was associated with a higher CI risk than supervisory work (aRR=1.99), and also found that security during the September response period was attributable for the majority of that risk. While seemingly small increase in risk of CI, the prevalence of CI in this group was still relatively high. One reason for smaller risk ratios may be that the supervisory group used as the reference category for our analysis, though representing a less exposed group, was still not truly "unexposed".

Our results underscore the pervasive risks in disaster response working environments and the surgical/nuisance masks can provide some protection across all WRA groups during the response. While this study examines the relationship between WRAs and CI, it cannot distinguish between specific types of pollutant, chemical, or particulate exposures. Furthermore, it is important to note that the effectiveness of a face mask depends on the quality of the filter material and fit to the face. For surgical masks, the loose fit significantly limits the effectiveness of their filter material, as gaps allow air to bypass the mask (Faridi et al., 2020; Pacitto et al., 2019). Yet, their relative comfort makes them more readily worn in cases of high heat or in cramped spaces such as in crevices between building pieces. In our study, surgical/nuisance dust mask usage was associated with a lower risk (aRR = 0.77) of CI. This indicates that compared to wearing nothing, wearing a mask is associated with a 23 % lower risk of CI even after adjusting for variation in WRA. Our results may imply that surgical/nuisance dust mask usage was effective for all responders who lacked a respirator, consistent both with the theory that the ambient air at the WTC sites was contaminated. Indeed, in some activities such as in enclosed spaces, the protective effectiveness of surgical/nuisance dust masks was sufficient to reduce CI risk to levels comparable to those of the supervision group (data not shown).

Though no existing studies have examined how surgical/nuisance dust mask usage mediates/moderates the exposure-cognition relationship in the WTC cohort, few studies have shown conflicting results regarding the protective effects of respirator use on respiratory outcomes. For instance, one study found that the number of days of exposure was the only significant predictor of respiratory and nose/throat symptoms among 319 WTC-exposed firefighters, despite also examining respirator use and job tasks (Feldman et al., 2004). A study among 96 male iron workers at the WTC indicated a correlation between the use of canister respirators and a reduction in new respiratory symptoms (adjusted OR=0.32, p = 0.052) (Skloot et al., 2004). Consistent with our results that surgical/nuisance dust mask usage was associated with a decreased risk of CI, a study of 9296 WTC rescue and recovery workers found that all types of respirators, including surgical/nuisance dust masks, played a protective role against respiratory symptoms, with half-face respirators providing the broadest protective effect across various symptoms (Antao et al., 2011). Of note, discrepancies in these results could be attributed to the different outcomes measured. For instance, Feldman et al. (2004) used a broader definition of nose and throat symptoms, encompassing any related symptoms, whereas Antao et al. (2011) applied a more restrictive definition of respiratory disease, only including symptoms such as shortness of breath, wheezing, chronic cough, upper respiratory symptoms, asthma, and COPD. In contrast to these previous studies, the present study considers the importance of mask usage to the risk of CI up to 20 years after exposure.

Attitudes affect choices around safety behaviors such as whether to wear surgical masks (Wong and Lee, 2016). In the WTC context, responders who perceived themselves at risk despite being told that the air was safe to breathe, such as engaging in WRAs with visible dust exposure or working in enclosed environments may have been more likely to wear masks. Responders in roles perceived as less hazardous, such as security or support, showed decreased mask usage. Surgical/nuisance dust mask usage appeared to carry a statistically significant benefit for all WRA groups, although its protective efficacy diminished in more hazardous

Table 5
Moderated Mediation Analysis of World Trade Center Response Activity (WRA) on Cognitive Impairment using Mask Usage as an Intermediary Variable.

Moderated-Intermediary Analysis Results					
WRA	**Predictor**	**aRR**	**Lower**	**Upper**	**P adjusted**
Supervision (reference)	Natural Indirect effect	1.00			
Supervision (reference)	Interaction → CI	1.00			
Cable Utility	Natural Indirect effect	0.99	0.95	1.03	0.519
Cable Utility	Interaction → CI	1.76	0.90	3.41	0.122
Debris Removal Steel	Natural Indirect effect	0.99	0.96	1.03	0.767
Debris Removal Steel	Interaction → CI	1.35	0.94	1.94	0.122
Enclosed	**Natural Indirect effect**	**0.92**	**0.85**	**0.99**	**0.050**
Enclosed	Interaction → CI	0.67	0.41	1.10	0.130
Morgue	Natural Indirect effect	0.95	0.89	1.02	0.205
Morgue	Interaction → CI	0.62	0.34	1.13	0.143
Search	Natural Indirect effect	0.99	0.94	1.03	0.562
Search	Interaction → CI	1.06	0.64	1.75	0.828
Security	Natural Indirect effect	1.04	0.94	1.14	0.511
Security	Interaction → CI	1.20	0.70	2.07	0.511
Support	Natural Indirect effect	1.14	0.90	1.45	0.332
Support	Interaction → CI	0.68	0.20	2.30	0.581
Non-Moderated Intermediary Analysis					
Supervision (reference)	Natural Indirect effect	1.00			
Cable Utility	Natural Indirect effect	1.01	0.99	1.04	0.309
Debris Removal Steel	**Natural Indirect effect**	**0.96**	**0.93**	**0.99**	**0.021**
Enclosed	**Natural Indirect effect**	**0.97**	**0.94**	**1.00**	**0.043**
Morgue	Natural Indirect effect	0.98	0.96	1.01	0.182
Search	**Natural Indirect effect**	**0.97**	**0.95**	**1.00**	**0.058**
Security	**Natural Indirect effect**	**1.05**	**1.01**	**1.10**	**0.018**
Support	**Natural Indirect effect**	**1.06**	**1.01**	**1.11**	**0.042**

Note: Natural Indirect Effect (NIE) of WRA on CI from counterfactual moderated intermediary analysis. The second row for each WRA, obtained from robust Poisson regression, represents the coefficient of the interaction term (indicated on the left side of the arrow) on CI (indicated on the right side of the arrow). All models are adjusted for age, gender, education, smoking, alcohol consumption, and total hours. aRR: multivariable-adjusted Rate Ratio; Lower: lower boundary of 95 % Confidence Interval; Upper: upper boundary of 95 % Confidence Interval; P adjusted: False Discovery Rate (FDR) adjusted p-value.

environments. The reasons for not wearing mask results showed that some people underestimated the pervasive CI risk during the response. They chose not to wear masks because they believed the air quality was safe and saw no need for one. Together, these results combined with prior work might imply that ambient air exposure may have contained more danger than originally believed and that using a respirator could have had a sizable impact on this population. However, discomfort and communication difficulties were frequently reported as barriers to mask use, which may explain why many responders opted for surgical/-nuisance dust masks or chose not to wear masks at all. This study emphasizes the importance of developing accessible, comfortable, and effective respirators for responders.

5. Limitations

As this is an observational study, it is worth noting that causality cannot be inferred from these analyses. This study's reliance on self-reported variables introduces potential recall bias, and the length of the questionnaire could have contributed to inconsistencies in responses, suggesting either a misunderstanding of the questions or respondent fatigue. We partially addressed these issues by verifying variable values against straightforward questions, such as whether participants had ever used a surgical/nuisance dust mask, to oversee the accuracy of reported first-week respiratory type usage. Additionally, we used the reported first arrival date to verify the working status during each response period. However, we found that adjusting for that via modifications mentioned above caused no real change to results, suggesting that this limitation may not be relevant. Notably, data about the type of respirator that was used was only available for a short period of time, and participants might have changed equipment subsequently. Our analysis was, therefore, limited to those who arrived within the first week and reported not using a respirator. As previously noted, excluded participants may have worn respirators and experienced greater exposure, thereby increasing the error estimates around the intermediary benefits of masks from this subsample. Additionally, we measured cognitive impairment (CI) at a single time point after exposure, making it unclear whether diminished risk of CI resulted from WTC exposure or pre-existing occupational or environmental factors. Future studies with pre-WTC cognitive assessments or detailed work histories could help to provide more clarity. While causality cannot be established in this cross-sectional study, other research links WTC exposure to increased incidence of dementia, supporting a temporal relationship with cognitive decline (Clouston et al., 2024). Future work might also seek to determine the relationship between mask usage and incidence of dementia.

5.1. Validation and contribution of NLP results

The variables "supervision," "enclosed environment," and "steel work" can be obtained from both NLP free text analysis and original structured variables. These variables were utilized to demonstrate how NLP outcomes can enhance a dataset by providing additional information. This is important for several reasons. First, 1224 participants were missing occupational code data, and 3220 provided broad occupational codes such as "police officer, military, engineers" while also offering free text descriptions. Second, in contrast to structured exposure data, the NLP analysis highlighted predominantly the absence of certain response activities but also introduced others (specificity= [0.99,1], sensitivity= [0.03–0.39], positive predictive value= [0.48–0.98] data not shown). For instance, among the first five participants in Supplemental Table **IV**, the steel activity label was identified through NLP analysis, despite all entries related to burning exposure indicating an absence (no). Among these, one participant's occupational code, "pipe-layers," corroborated the NLP finding. The remaining data points were either missing, categorized under broad occupational titles such as "police officer," or associated with different activities. Similarly, participants 6–10 were categorized under the 'enclosed' label based on NLP results, and participants 11–15 were identified with 'supervision' as their activity label from NLP findings. This study provides an example of an NLP application that can be used to develop future occupational exposure matrices for cognitive health.

5.2. Impact

Catastrophes like the U.S. Miami tower collapse (Simons et al., 2022) or the Plasco building collapse in Tehran (Ahmadi et al., 2020), emphasize the importance of safety to future disasters. Stringent and proactive safety measures and policies are critical to ensuring comprehensive public health protection during all stages of disaster response. The U.S. National Institute for Occupational Safety and Health (NIOSH)

only recognizes approved respirators as personal protective equipment (PPE) for air pollution and surgical masks are considered the least effective methods for reducing pollutant exposure (National Institute for Occupational Safety and Health NIOSH, 2023). However, sometimes response efforts may be long-lasting, conducted by responders or civilians lacking access to respirators, conducted outdoors in the fresh air, deemed safe by government officials, or affected by problems relating to comfort-related barriers as was the case with WTC response efforts. In such cases, large groups of responders may opt to forgo using PPE. In such cases, our findings indicate that surgical/nuisance dust masks may still offer a degree of protection against unforeseen exposures. Beyond building collapse disasters, future disasters with high pollutant levels should consider public health interventions (McDonald and Horwell, 2020). Agencies may have a duty to warn people involved in clean-up about the health risks associated with such clean-up sites and recommend facemasks as a protective measure to mitigate particulate matter exposure.

5.3. Institution and ethics approval and informed consent

The Stony Brook University Committee on Research Involving Human Subjects reviewed and approved this study annually. The participants or their legally authorized representatives provided informed written consent.

Funding

This work is supported by the National Institutes of Health (NIH/NIA R01 AG049953) and by the Centers for Disease Control and Prevention (CDC/NIOSH).

CRediT authorship contribution statement

Mann Frank D: Writing – review & editing, Methodology. **Richmond Lauren L:** Writing – review & editing, Methodology. **Meliker Jaymie:** Writing – review & editing, Methodology. **Yang Yuan:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Conceptualization. **Clouston Sean A.P.:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Funding acquisition, Data curation, Conceptualization. **Luft Benjamin J:** Writing – review & editing, Data curation. **Carr Melissa A:** Writing – review & editing, Data curation. **Babalola Tesleem:** Writing – review & editing. **Smith Dylan:** Writing – review & editing, Methodology. **Kritikos Minos:** Writing – review & editing, Methodology.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work, YY used ChatGPT to enhance the readability of the language by rephrasing or editing text. ChatGPT was utilized solely for rephrasing purposes and not for generative writing. Following its use, all authors thoroughly reviewed and made edits to the content.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

This work is supported by the National Institutes of Health (NIH/NIA R01 AG049953) and by the Centers for Disease Control and Prevention (CDC/NIOSH 75D301–22-C-15522).

Disclaimer

None.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.neuro.2025.02.002.

Data availability

Data will be made available on request.

References

Ahmadi, M.T., Aghakouchak, A.A., Mirghaderi, R., Tahouni, S., Garivani, S., Shahmari, A., Epackachi, S., 2020. Collapse of the 16-story plasco building in tehran due to fire. Fire Technol. 56 (2), 769–799. https://doi.org/10.1007/s10694-019-00903-y.

Antao, V.C., Pallos, L.L., Shim, Y.K., Sapp, J.H., 2nd, Brackbill, R.M., Cone, J.E., Stellman, S.D., Farfel, M.R., 2011. Respiratory protective equipment, mask use, and respiratory outcomes among World Trade Center rescue and recovery workers. Am. J. Ind. Med. 54 (12), 897–905. https://doi.org/10.1002/ajim.21009.

Caubet, M., Samoilenko, M., Gervais, J., Lefebvre, G., 2023. ExactMed: Exact Mediation Analysis for Binary Outcomes. In https://CRAN.R-project.org/package=ExactMed.

Centers for Disease Control and Prevention (CDC), 2002. Use of respiratory protection among responders at the World Trade Center site–New York City, September 2001. *MMWR Morb. Mortal. Wkly Rep., 51 Spec. No* 6–8.

Cersonsky, T.E.K., Mechery, S., Carper, M.M., Thompson, L., Lee, A., Alber, J., Sarkar, I. N., Brick, L.A.D., 2022. Using the Montreal cognitive assessment to identify individuals with subtle cognitive decline. Neuropsychology 36 (5), 373–383. https://doi.org/10.1037/neu0000820.

Chen, W., Qian, L., Shi, J., Franklin, M., 2018. Comparing performance between log-binomial and robust Poisson regression models for estimating risk ratios under model misspecification. BMC Med. Res. Methodol. 18 (1). https://doi.org/10.1186/s12874-018-0519-5.

Clouston, S.A.P., Hall, C.B., Kritikos, M., Bennett, D.A., DeKosky, S., Edwards, J., Finch, C., Kreisl, W.C., Mielke, M., Peskind, E.R., Raskind, M., Richards, M., Sloan, R. P., Spiro, A., 3rd, Vasdev, N., Brackbill, R., Farfel, M., Horton, M., Lowe, S., Luft, B. J., 2022. Cognitive impairment and World Trade Centre-related exposures. Nat. Rev. Neurol. 18 (2), 103–116. https://doi.org/10.1038/s41582-021-00576-8.

Clouston, S.A., Kotov, R., Pietrzak, R.H., Luft, B.J., Gonzalez, A., Richards, M., Ruggero, C.J., Spiro 3rd, A., Bromet, E.J., 2016. Cognitive impairment among World Trade Center responders: long-term implications of re-experiencing the 9/11 terrorist attacks. Alzheimers Dement 4, 67–75. https://doi.org/10.1016/j.dadm.2016.08.001.

Clouston, S.A.P., Mann, F.D., Meliker, J., Kuan, P.-F., Kotov, R., Richmond, L.L., Babalola, T., Kritikos, M., Yang, Y., Carr, M.A., Luft, B.J., 2024. Incidence of dementia before age 65 years among world trade center attack responders. e2416504-e2416504 JAMA Netw. Open 7 (6). https://doi.org/10.1001/jamanetworkopen.2024.16504.

Clouston, S., Pietrzak, R.H., Kotov, R., Richards, M., Spiro, A., 3rd, Scott, S., Deri, Y., Mukherjee, S., Stewart, C., Bromet, E., Luft, B.J., 2017. Traumatic exposures, posttraumatic stress disorder, and cognitive functioning in World Trade Center responders. Alzheimers Dement (N. Y 3 (4), 593–602 https://doi.org/https://doi.org/10.1016%2Fj.trci.2017.09.001.

Dasaro, C.R., Holden, W.L., Berman, K.D., Crane, M.A., Kaplan, J.R., Lucchini, R.G., Luft, B.J., Moline, J.M., Teitelbaum, S.L., Tirunagari, U.S., Udasin, I.G., Weiner, J.H., Zigrossi, P.A., Todd, A.C., 2017. Cohort profile: world trade center health program general responder cohort. Int J. Epidemiol. 46 (2), e9. https://doi.org/10.1093/ije/dyv099.

Duncan, S., Bodurtha, P., Naqvi, S., 2021. The protective performance of reusable cloth face masks, disposable procedure masks, KN95 masks and N95 respirators: filtration and total inward leakage. PLoS One 16 (10), e0258191. https://doi.org/10.1371/journal.pone.0258191.

Duong, S., Patel, T., Chang, F., 2017. Dementia: what pharmacists need to know. Can. Pharm. J. (Ott.) 150 (2), 118–129. https://doi.org/10.1177/1715163517690745.

Faridi, S., Nodehi, R.N., Sadeghian, S., Tajdini, M., Hoseini, M., Yunesian, M., Nazmara, S., Hassanvand, M.S., Naddafi, K., 2020. Can respirator face masks in a developing country reduce exposure to ambient particulate matter? J. Expo. Sci. Environ. Epidemiol. 30 (4), 606–617. https://doi.org/10.1038/s41370-020-0222-6.

Feldman, D.M., Baron, S.L., Bernard, B.P., Lushniak, B.D., Banauch, G., Arcentales, N., Kelly, K.J., Prezant, D.J., 2004. Symptoms, respirator use, and pulmonary function changes among New York City firefighters responding to the World Trade Center disaster. Chest 125 (4), 1256–1264. https://doi.org/10.1378/chest.125.4.1256.

Hakim, S.A., Moamen, M., 2018. Health hazards and safety culture description among cable manufacture egyptian workers. Egypt. J. Occup. Med. 42 (3), 411–426. https://doi.org/10.21608/ejom.2018.12206.

Harber, P., Leroy, G., 2017. Feasibility and Utility of Lexical Analysis for Occupational Health Text. J. Occup. Environ. Med 59 (6), 578–587. https://doi.org/10.1097/JOM.0000000000001035.

Kelley, A.S., McGarry, K., Gorges, R., Skinner, J.S., 2015. The burden of health care costs for patients with dementia in the last 5 years of life. Ann. Intern Med 163 (10), 729–736. https://doi.org/10.7326/m15-0381.

Kodros, J.K., O'Dell, K., Samet, J.M., L'Orange, C., Pierce, J.R., Volckens, J., 2021. Quantifying the health benefits of face masks and respirators to mitigate exposure to severe air pollution. e2021GH000482 Geohealth 5 (9). https://doi.org/10.1029/2021gh000482.

Kritikos, M., Diminich, E.D., Meliker, J., Mielke, M., Bennett, D.A., Finch, C.E., Gandy, S. E., Carr, M.A., Yang, X., Kotov, R., Kuan, P.F., Bromet, E.J., Clouston, S.A.P., Luft, B. J., 2023. Plasma amyloid beta 40/42, phosphorylated tau 181, and neurofilament light are associated with cognitive impairment and neuropathological changes among World Trade Center responders: A prospective cohort study of exposures and cognitive aging at midlife. Alzheimers Dement (Amst. 15 (1), e12409. https://doi.org/10.1002/dad2.12409.

Kritikos, M., Gandy, S.E., Meliker, J.R., Luft, B.J., Clouston, S.A.P., 2020. Acute versus chronic exposures to inhaled particulate matter and neurocognitive dysfunction: pathways to Alzheimer's disease or a related dementia. J. Alzheimers Dis. 78 (3), 871–886. https://doi.org/10.3233/JAD-200679.

Li, G.J., Zhang, L.-l, Lu, L., Wu, P., Zheng, W., 2004. Occupational exposure to welding fume among welders: alterations of manganese, iron, zinc, copper, and lead in body fluids and the oxidative stress status. J. Occup. Environ. Med. 46 (3), 241–248. https://doi.org/10.1097/01.jom.0000116900.49159.03.

Lippmann, M., Cohen, M.D., Chen, L.C., 2015. Health effects of World Trade Center (WTC) Dust: An unprecedented disaster's inadequate risk management. Crit. Rev. Toxicol. 45 (6), 492–530. https://doi.org/10.3109/10408444.2015.1044601.

Livingston, G., Huntley, J., Liu, K.Y., Costafreda, S.G., Selbæk, G., Alladi, S., Ames, D., Banerjee, S., Burns, A., Brayne, C., 2024. Dementia prevention, intervention, and care: 2024 report of the Lancet standing Commission. Lancet 404 (10452), 572–628.

Luis, C.A., Keegan, A.P., Mullan, M., 2009. Cross validation of the Montreal Cognitive Assessment in community dwelling older adults residing in the Southeastern US. Int J. Geriatr. Psychiatry 24 (2), 197–201. https://doi.org/10.1002/gps.2101.

MacIntyre, C.R., Wang, Q., Seale, H., Yang, P., Shi, W., Gao, Z., Rahman, B., Zhang, Y., Wang, X., Newall, A.T., Heywood, A., Dwyer, D.E., 2013. A randomized clinical trial of three options for n95 respirators and medical masks in health workers. Am. J. Respir. Crit. Care Med. 187 (9), 960–966. https://doi.org/10.1164/rccm.201207-1164OC.

McDonald, F., Horwell, C.J., 2020. Air pollution disasters: liability issues in negligence associated with the provision of personal protective interventions (Facemasks). Disaster Med. Public Health Prep. 15 (3), 367–373. https://doi.org/10.1017/dmp.2020.37.

Nash, J., 2002. Cleaning up after 9/11: respirators, power, and politics, 2002, May 29. EHS Today. ⟨https://www.ehstoday.com/ppe/respirators/article/21913186/cleaning-up-after-9-11-respirators-power-and-politics⟩, 2002, May 29.

Nasreddine, Z.S., Phillips, N.A., Bedirian, V., Charbonneau, S., Whitehead, V., Collin, I., Cummings, J.L., Chertkow, H., 2005. The Montreal Cognitive Assessment, MoCA: a brief screening tool for mild cognitive impairment. J. Am. Geriatr. Soc. 53 (4), 695–699. https://doi.org/10.1111/j.1532-5415.2005.53221.x.

National Institute for Occupational Safety and Health (NIOSH). (2023). *Community use of face masks and respirators to prevent respiratory infections*. Retrieved January 16 from ⟨https://www.cdc.gov/niosh/topics/publicppe/community-ppe.html?utm_source=chatgpt.com#print⟩.

Nichols, E., Steinmetz, J.D., Vollset, S.E., Fukutaki, K., Chalek, J., Abd-Allah, F., Abdoli, A., Abualhasan, A., Abu-Gharbieh, E., Akram, T.T., Al Hamad, H., Alahdab, F., Alanezi, F.M., Alipour, V., Almustanyir, S., Amu, H., Ansari, I., Arabloo, J., Ashraf, T., Vos, T., 2022. Estimation of the global prevalence of dementia in 2019 and forecasted prevalence in 2050: an analysis for the Global Burden of Disease Study 2019. Lancet Public Health 7 (2), e105–e125. https://doi.org/10.1016/S2468-2667(21)00249-8.

Pacitto, A., Amato, F., Salmatonidis, A., Moreno, T., Alastuey, A., Reche, C., Buonanno, G., Benito, C., Querol, X., 2019. Effectiveness of commercial face masks to reduce personal PM exposure. Sci. Total Environ. 650, 1582–1590. https://doi.org/10.1016/j.scitotenv.2018.09.109.

Radonovich, L.J., Jr, Simberkoff, M.S., Bessesen, M.T., Brown, A.C., Cummings, D.A.T., Gaydos, C.A., Los, J.G., Krosche, A.E., Gibert, C.L., Gorse, G.J., Nyquist, A.-C., Reich, N.G., Rodriguez-Barradas, M.C., Price, C.S., Perl, T.M., investigators, f. t. R, 2019. N95 respirators vs medical masks for preventing influenza among health care personnel: a randomized clinical trial. JAMA 322 (9), 824–833. https://doi.org/10.1001/jama.2019.11645.

Rajakumar, J.P.P., Choi, J.M., 2023. Helmet-mounted real-time toxic gas monitoring and prevention system for workers in confined places. Sensors 23 (3), 1590. https://doi.org/10.3390/s23031590.

Reissman, D.B., Howard, J., 2008. Responder safety and health: preparing for future disasters. Mt Sinai J. Med 75 (2), 135–141. https://doi.org/10.1002/msj.20024.

Rosen, R., Shao, Y., Zhang, Q., Bao, J., Zhang, Y., Masurkar, A., Wisniewski, T., Urban, N., Reibman, J., 2022. Cognitive function among world trade center-exposed community members with mental health symptoms. Int J. Environ. Res Public Health 19 (6). https://doi.org/10.3390/ijerph19063440.

Sainio, M.A., 2015. Chapter 7 - Neurotoxicity of solvents. In: Lotti, M., Bleecker, M.L. (Eds.), Handbook of Clinical Neurology, 131. Elsevier, pp. 93–110. https://doi.org/10.1016/B978-0-444-62627-1.00007-X.

Simons, R., Xiao, Y., Evenchik, A., Barreto, A., 2022. Champlain towers south collapse: frequency, governance and liability issues. J. Sustain. Real. Estate 14 (1), 57–74. https://doi.org/10.1080/19498276.2022.2104346.

Skloot, G., Goldman, M., Fischler, D., Goldman, C., Schechter, C., Levin, S., Teirstein, A., 2004. Respiratory symptoms and physiologic assessment of ironworkers at the World Trade Center disaster site. Chest 125 (4), 1248–1255. https://doi.org/10.1378/chest.125.4.1248.

Smith, E., Holmes, L., Larkin, B., 2021. Health trends among 9/11 responders from 2011-2021: a review of world trade center health program statistics. Prehosp. Disaster Med 36 (5), 621–626. https://doi.org/10.1017/S1049023X21000881.

Stern, F., Haring-Sweeney, M., 1997. Proportionate mortality among unionized construction operating engineers. Am. J. Ind. Med 32 (1), 51–65. https://doi.org/10.1002/(sici)1097-0274(199707)32:1< 51::aid-ajim7> 3.0.co;2-u.

Valeri, L., Vanderweele, T.J., 2013. Mediation analysis allowing for exposure-mediator interactions and causal interpretation: theoretical assumptions and implementation with SAS and SPSS macros. Psychol. Methods 18 (2), 137–150. https://doi.org/10.1037/a0031034.

Wong, W., 2020. Economic burden of Alzheimer disease and managed care considerations. Am. J. Manag Care 26 (8), S177–S183. https://doi.org/10.37765/ajmc.2020.88482.

Wong, D.B., Lee, S.G., 2016. Modelling the predictors of intention in workplace safety compliance of a multi-ethnic workforce. Saf. Sci. 88, 155–165. https://doi.org/10.1016/j.ssci.2016.05.003.