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World Trade Center exposure, post-traumatic stress disorder, and subjective cognitive concerns in a cohort of rescue/recovery workers

Singh A, Zeig-Owens R, Hall CB, Liu Y, Rabin L, Schwartz T, Webber MP, Appel D, Prezant DJ. World Trade Center exposure, post-traumatic stress disorder, and subjective cognitive concerns in a cohort of rescue/recovery workers.

Objective: To determine whether World Trade Center (WTC)-exposure intensity and post-traumatic stress disorder (PTSD) are associated with subjective cognitive change in rescue/recovery workers.
Method: The population included 7875 rescue/recovery workers who completed a subjective cognition measure, the Cognitive Function Instrument (CFI), between 3/1/2018 and 2/28/2019 during routine monitoring, indicating whether they had experienced cognitive and functional difficulties in the past year. Higher scores indicated greater self-perceived cognitive change. Probable PTSD, depression, and alcohol abuse were evaluated by validated mental health screeners. Logistic regression assessed the associations of WTC exposure and current PTSD with top-quartile (≥2) CFI score, and of early post-9/11 PTSD with top-quartile CFI in a subpopulation (N = 6440). Models included demographics, smoking, depression, and alcohol abuse as covariates.
Results: Mean age at CFI completion was 56.7 ± 7.7 (range: 36–81). Participants with high-intensity WTC exposure had an increased likelihood of top-quartile CFI score (odds ratio[OR] vs. low exposure: 1.32, 95%CI: 1.07–1.64), controlling for covariates. Current and early PTSD were both associated with top-quartile CFI (OR: 3.25, 95%CI: 2.53–4.19 and OR: 1.56, 95%CI: 1.26–1.93) respectively.
Conclusions: High-intensity WTC exposure was associated with self-reported cognitive change 17 years later in rescue/recovery workers, as was PTSD. Highly WTC-exposed subgroups may benefit from additional cognitive evaluation and monitoring of cognition over time.

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Key words: stress disorders; post-traumatic; cognitive dysfunction; mental health; occupational health

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Significant outcomes

- We assessed subjective cognitive change in a cohort of World Trade Center (WTC) first responders 17 years after 9/11/2001 (9/11). The cognitive concerns that were most commonly reported were memory-related.
- WTC first responders who had high-intensity WTC exposure were more likely to report subjective cognitive concerns than were responders who had lower-level WTC exposure.
- We observed a cross-sectional association between current probable post-traumatic stress disorder (PTSD) and subjective cognitive concerns, and also found that probable PTSD in the year after 9/11 was associated with a greater odds of subjective cognitive concerns 17 years later.

Limitations

- We used a subjective cognitive measure, the validated Cognitive Function Instrument, to assess participants' cognition instead of an objective measure.
- Participants' baseline cognitive function was not assessed.
- The majority of participants with current probable PTSD (92%) had concurrent probable depression.

Introduction

Cognitive impairment is a growing public health concern in the United States, given an aging population (1–3). Among US adults aged ≥ 45 years surveyed between 2015 and 2016, ~11% reported experiencing subjective cognitive decline in the previous year (4). In older adults, subjective cognitive decline was associated with an increased likelihood of biomarker abnormalities consistent with Alzheimer's disease pathology, as well as an increased risk for future pathologic cognitive decline and dementia (5–8).

Age, depression, and certain socioeconomic factors are well-established risk factors for cognitive impairment and dementia (9–11). Previous studies have also found post-traumatic stress disorder (PTSD) to be associated with reduced cognitive function (12–14) and deficits in multiple cognitive domains (12, 15, 16). Notably, PTSD earlier in life has been linked to worse cognitive performance in later years (12, 14). A recent study in a cohort of 1193 World Trade Center (WTC)-exposed first responders showed that participants had worse performance on the neuropsychological battery Cogstate when compared with normative data (15) and that PTSD symptoms, measured using the PTSD Checklist (PCL), were associated with worse cognitive function.

We previously reported that 10% of WTC-exposed Fire Department of the City of New York (FDNY) rescue/recovery workers screened positive for PTSD in the year following 9/11/2001 (9/11) (17), and that higher-intensity WTC exposure, defined as early arrival at the WTC site, was associated with more PTSD symptoms (18, 19). As this disaster-exposed cohort ages, the need to assess the effect of potential risk factors for cognitive decline becomes imperative.

We added a subjective cognitive measure to the FDNY health monitoring questionnaire in order to identify the prevalence of and risk factors for self-reported cognitive concerns. The aims of the current investigation were to identify the most frequently reported types of cognitive concerns 17 years post-9/11 among FDNY WTC-exposed rescue/recovery workers, and to assess whether WTC exposure intensity and PTSD are associated with self-reported cognitive deficits.

Methods

Study population

The source population for this study included firefighters and Emergency Medical Service workers (EMS) who were actively employed by FDNY on 9/11 and first arrived at the WTC site between 9/11-9/24/2001 (N = 11 483). Both active and retired WTC-exposed FDNY firefighters and EMS undergo medical monitoring at FDNY every 12–18 months; these visits include the administration of health questionnaires as well as a physical examination. In 2018, a self-administered subjective measure of cognition and function, the Cognitive Function Instrument (CFI) (20–22),was added to the medical monitoring questionnaire. The final study population was restricted to individuals who completed the CFI during a routine medical monitoring visit that took place between 3/1/2018-2/28/2019 (N = 7875). All participants provided written informed consent. The Montefiore Medical Center/Albert Einstein College of Medicine Institutional Review Board approved this study.

Participant characteristics

Participants' race, sex, and age were taken from the FDNY employee database. Smoking status (current, former, or never smoker) was reported during routine medical monitoring via the self-administered health questionnaire. Individuals who consistently reported never smoking were categorized as never smokers, and those who reported past or current smoking on their most recent monitoring examination were classified as former or current smokers respectively. Participants' education level was obtained from the same questionnaire.

WTC exposure

WTC exposure was defined according to participants' time of initial arrival at the WTC site. During their first post-9/11 medical monitoring examination, participants indicated whether they had arrived at the site on the morning of 9/11 (high-intensity exposure), the afternoon of 9/11 or on 9/12/2001 (moderate exposure), or between 9/13–9/24/2001 (low exposure).

PTSD symptoms, depressive symptoms, and alcohol abuse

We assessed PTSD symptoms, depressive symptoms, and harmful alcohol consumption via self-administered health questionnaires. Early post-9/11 PTSD symptoms were assessed using a modified version of the PTSD Checklist (PCL-m) (23). In the PCL-m, 14 questions were modified to fit the context of 9/11, and the answer choices were binary ('yes'/'no'). A positive score on the PCL-m required symptoms within each of the three DSM-IV-TR PTSD symptom groups (re-experiencing, arousal, and avoidance). In our population, the modified measure was found to be similar to the standard 17 item PCL (18, 24). Depressive symptoms and alcohol abuse were not measured at that time. From 2005 onward, the FDNY monitoring questionnaire included the PCL Specific (PCL-S) (23, 25, 26), as well as the Center for Epidemiologic Studies Depression Scale (CES-D) (27), and the Alcohol Use Disorder Identification Test (AUDIT) (28). A modified version of the Life Events Checklist (29) was included in the monitoring questionnaire along with the PCL-S. The list of potential traumatic experiences was condensed into six items, and WTC exposure was added as an option. In a subsequent question, as part of the PCL-S, participants identified the index event by indicating which event was most traumatic to them. Participants who screened positive for PTSD on a monitoring examination in the year after 9/11 were considered to have early post-9/11 probable PTSD, and those who had a PCL-S score ≥ 44, CES-D score ≥ 16 or AUDIT score ≥ 8 between 3/1/2018-2/28/2019 were considered to have current probable PTSD, probable depression, or probable alcohol abuse respectively. Henceforth, we refer to these conditions as early post-9/11 PTSD, current PTSD, current depression, and current alcohol abuse.

Subjective cognitive function

The CFI, a validated, 14-item measure of perceived cognitive and functional change over the past year (20), was added to the FDNY monitoring questionnaire on 3/1/2018. The CFI was developed to identify early cognitive changes in individuals without clinical impairment, who may eventually progress to dementia; it has been shown to be sensitive to decline in longitudinal studies of older adults (20, 30, 31). Individuals responded 'Yes', 'Maybe', or 'No' when asked if certain aspects of their cognition and functional abilities had worsened compared to one year ago; responses were scored as 1, 0.5, and 0 points respectively. Each participant received a total score between 0 and 14, with higher scores corresponding to greater self-assessed cognitive change. We also calculated an adjusted CFI score by excluding participant responses to a question about social isolation, as this question existed in some form on both the PCL and the CES-D. Possible values for the adjusted CFI score ranged from 0 to 13.

Statistical analyses

Demographics and other characteristics of the WTC-exposed FDNY cohort and the final study population were assessed as proportions and means. The proportion of positive answers for each item on the CFI was calculated among those in each of the three WTC exposure groups and among those with concurrent PTSD and depression, those with current PTSD but no depression, those with current depression but no PTSD, and those with neither condition. To evaluate a potential association between WTC exposure and subjective cognitive concerns, we fit a logistic regression model of WTC exposure level predicting elevated CFI score (top quartile), controlling only for age, sex, race, education level, work assignment (firefighter or EMS) on 9/11, and smoking status and then performed multivariable logistic regression analyses that included the mental health conditions described above.

Multivariable logistic regression analyses tested the associations of PTSD with elevated CFI score; we first evaluated the association between current PTSD and elevated CFI score and then tested whether early post-9/11 PTSD was related to this outcome in the subpopulation of those who had had a medical monitoring examination in the year after 9/11 (9/11/2001-9/10/2002) ($N = 6440$), controlling for the demographic variables, smoking status, work assignment on 9/11, WTC exposure level, current depression, and alcohol abuse.

Because risk of cognitive decline is known to increase with age, in secondary analyses, we repeated the logistic regression analyses described above in two subgroups defined by age at the time

of CFI completion, examining the associations of WTC exposure level and PTSD with elevated CFI scores in younger (aged 36–55) and older (aged 56–81) participants. Sensitivity analyses were then performed, including one which assessed whether WTC exposure intensity or PTSD was associated with having a CFI score in the top decile, and another that assessed the associations of WTC exposure and PTSD with top-quartile-adjusted CFI score (CFI score excluding the social isolation question). These logistic models included age, sex, race, education level, work assignment on 9/11, smoking status, and current depression and alcohol abuse. We selected these covariates because they are known correlates of mental health conditions and/or cognitive problems.

SAS version 9.4 was used to analyze the data. All reported *P*-values are two-sided and considered significant when <0.05.

Results

Population characteristics

Characteristics of the source population and the final study cohort are presented in Table 1. The mean age of rescue/recovery workers who took the CFI was 56.7 ± 7.7 (range: 36–81) years, and the median CFI score was 0 (interquartile range [IQR]: 0–2, range: 0–14). The study population was similar to the source population in terms of age, WTC exposure, and education level, but had a slightly greater proportion of individuals who worked as firefighters on 9/11 (Table 1), and a lower proportion of individuals who screened positive for depression on their most recent medical monitoring examination.

Of the 638 participants with current PTSD, 538 (84.3%) indicated that their index event was WTC rescue/recovery work, although 473 (74.1%) reported multiple traumatic life experiences. Twenty-two per cent of the current PTSD subgroup who had received medical monitoring the year after 9/11 (106/482) had early post-9/11 PTSD. We also noted that 584 individuals with current PTSD had concurrent depression (91.5%).

Table 2 shows the individual CFI questions and, for each question, the proportion of participants who gave a positive answer. Fig. 1 displays levels of endorsement of the individual CFI questions in the three WTC exposure groups (Fig. 1a) and in participants with (i) concurrent PTSD and depression ($N = 584$), (ii) current PTSD but no depression ($N = 54$), (iii) current depression but no PTSD ($N = 738$), and (iv) neither PTSD nor depression ($N = 6499$) (Fig. 1b). Approximately 7.8% of the study cohort, 10.5% of participants with high-level WTC exposure, and 38.4% of participants with concurrent PTSD and depression, responded 'yes' when asked about having substantial memory decline in the past year. The most common memory-related complaints were increased reliance on written reminders (19.0% of the cohort) and difficulty recalling names and words (14.2%). Among those classified as having high WTC exposure, 24.0% reported increased reliance on written reminders and 18.2% reported difficulty recalling names and words, vs. 18.1% and 13.5% of the moderate exposure group and 17.2% and 12.6% of the low exposure group respectively (Fig. 1a). The majority of participants

Table 1. Population characteristics

Variable	WTC-exposed FDNY firefighters and EMS $N = 11\ 483$	Study population $N = 7875$
Age on 9/11	39.7 ± 7.7	39.7 ± 7.6
Age at subjective cognitive assessment, *N* (%)		
30–39	–	66 (0.8)
40–49	–	1400 (17.8)
50–59	–	3480 (44.2)
60–69	–	2525 (32.1)
70–79	–	399 (5.1)
80+	–	5 (0.1)
Sex, *N* (%)		
Male	11 157 (97.2)	7682 (97.5)
Female	326 (2.8)	193 (2.5)
Race, *N* (%)		
White	10 132 (88.2)	7064 (89.7)
Black	579 (5.0)	320 (4.1)
Hispanic	704 (6.1)	444 (5.6)
Other	68 (0.6)	47 (0.6)
World Trade Center site arrival time, *N* (%)		
Morning of 9/11	1986 (17.3)	1337 (17.0)
Afternoon on 9/11–9/12	7816 (68.1)	5423 (68.9)
9/13–9/24	1681 (14.6)	1115 (14.2)
Work assignment on 9/11, *N* (%)		
Firefighter	9849 (85.7)	6901 (87.6)
EMS	1634 (14.2)	974 (12.4)
Education level, *N* (%)		
High school	2200 (19.5)†	1465 (18.6)
Some college	4687 (41.2)†	3258 (41.4)
Associate's Degree	1318 (11.7)†	941 (12.0)
Bachelor's Degree	3070 (27.2)†	2211 (28.1)
Smoking status, *N* (%)		
Never	7385 (64.3)‡	5197 (66.0)
Former	3593 (31.3)‡	2444 (31.0)
Current	499 (4.3)‡	234 (3.0)
Early post-9/11 PTSD	877 (9.7)§	609 (9.5)‡‡
Current PTSD	1065 (9.4)¶	638 (8.1)
Current depression	2134 (18.8)††	1322 (16.8)
Current alcohol abuse	957 (8.4)††	584 (7.4)

†$N = 11\ 275$.
‡$N = 11\ 477$.
§$N = 9054$.
¶$N = 11\ 368$.
††$N = 11\ 363$.
‡‡$N = 6440$.

Table 2. Participants who responded 'yes' to CFI questions

Question	All (N = 7875) N (%)
1. Compared to one year ago, do you feel that your memory has declined substantially?	610 (7.8)
2. Do others tell you that you tend to repeat questions over and over?	502 (6.4)
3. Have you been misplacing things more often?	730 (9.3)
4. Do you find that lately you are relying more on written reminders (e.g., shopping lists, calendars)?	1495 (19.0)
5. Do you need more help from others to remember appointments, family occasions or holidays?	741 (9.4)
6. Do you have more trouble recalling names, finding the right word, or completing sentences?	1116 (14.2)
7. Do you have more trouble driving (e.g., do you drive more slowly, have more trouble at night, tend to get lost, have accidents)?	430 (5.5)
8. Do you have more difficulty managing money (e.g., paying bills, calculating change, completing tax forms)?	229 (2.9)
9. Are you less involved in social activities?	765 (9.7)
10. Has your work performance (paid or volunteer) declined significantly compared to one year ago?	374 (4.8)
11. Do you have more trouble following the news, or the plots of books, movies or TV shows, compared to one year ago?	284 (3.6)
12. Are there any activities (e.g., hobbies, such as card games, crafts) that are substantially more difficult for you now compared to one year ago?	283 (3.6)
13. Are you more likely to become disoriented, or get lost, for example when traveling to another city?	186 (2.4)
14. Do you have more difficulty using household appliances (such as the washing machine, VCR or computer)?	98 (1.2)

with concurrent PTSD and depression endorsed increased reliance on written reminders and difficulty recalling names and words (60.8% and 54.3%, respectively), compared with individuals who had current PTSD only (46.3% and 24.1%, respectively), those who had current depression but no current PTSD (41.6% and 33.9%, respectively), and those who had neither current depression nor PTSD (12.4% and 8.3%, respectively). The majority of individuals in the concurrent PTSD and depression group also reported social isolation (56.0%), compared with 16.7% of the group with current PTSD only, 30.9% of the group with current depression only and 3.1% of individuals who had neither mental health condition.

WTC exposure and elevated CFI score

A logistic regression model that controlled for demographic variables, work assignment, and smoking status, but not for any of the mental health conditions (PTSD, depression and alcohol abuse) showed that both high- and moderate-level WTC exposures were associated with elevated CFI scores (≥2) (odds ratio [OR] vs. low exposure: 1.67, 95% CI: 1.39–2.01 and 1.23, 95% CI: 1.05–1.44, respectively) (Table 3). In the logistic model that controlled for the mental health variables as well as demographics, work assignment, and smoking, high WTC exposure remained independently associated with elevated CFI scores (Table 4), although the association was attenuated.

PTSD and elevated CFI score

We observed a strong cross-sectional association between PTSD and elevated CFI scores (Table 4A). Participants with current PTSD were more than three times as likely to have a CFI score in the top quartile as those who did not screen positive (OR: 3.25, 95% CI: 2.53–4.19), after controlling for current depression, current alcohol abuse, demographic characteristics, work assignment, smoking status, and WTC exposure level.

Individuals who had early post-9/11 PTSD were more likely to have an elevated CFI score than those who did not have PTSD in the year after 9/11 (OR: 1.56, 95% CI: 1.26-1.93), controlling for current depression and the other covariates (Table 4B).

Secondary analysis

Twenty-four per cent (N = 857) of participants who were aged 36–55 when taking the CFI scored ≥ 2. In these participants, high-intensity WTC exposure predicted elevated CFI score in a logistic model that controlled for demographic characteristics, work assignment, and smoking status (OR vs. low-level exposure: 1.52, 95% CI: 1.15–2.00). Once current PTSD, depression, and alcohol abuse were included in the logistic model, the association between high-intensity exposure and elevated CFI score was no longer statistically significant (OR: 1.18, 95% CI: 0.85–1.63), but a strong association remained between current PTSD and the outcome (OR: 3.73, 95% CI: 2.56–5.45). Logistic regression analysis showed a borderline significant association between early post-9/11 PTSD and elevated CFI score (OR: 1.40, 95% CI: 1.00–1.96) in the subgroup of younger participants with available early post-9/11 measurements.

CFI scores ≥ 2 were observed in 28% (N = 1199) of individuals who were over age 55 at the time of assessment. High-intensity WTC exposure was also predictive of elevated CFI scores in individuals over 55, when controlling for demographic characteristics, work assignment and smoking status (OR vs. low-level exposure: 1.80, 95% CI: 1.41–2.30). High WTC exposure remained significantly associated with elevated

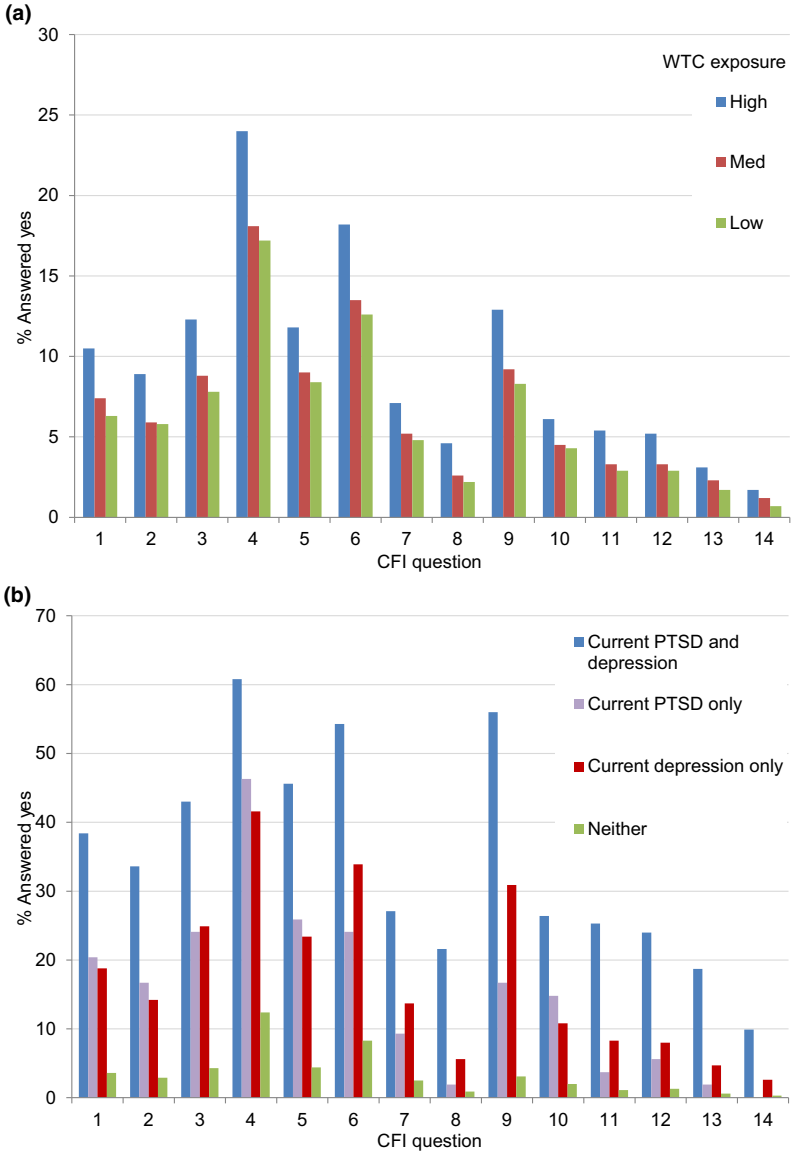

Fig. 1. Levels of endorsement of CFI questions. Panel a shows the proportion of participants in the high (blue), moderate (red), and low (green) WTC exposure groups who endorsed the individual CFI questions. Panel b shows what proportion of participants with current PTSD and depression (blue), current PTSD but no current depression (purple), current depression but no current PTSD (red), and neither current PTSD nor current depression (green) endorsed each question. The question numbers on the *x*-axes for both panels correspond to the questions in Table 2.

Table 3. Logistic regression analysis of World Trade Center (WTC) exposure intensity predicting elevated (top quartile) Cognitive Function Instrument score†

Variable	Odds ratio	95% Confidence interval
WTC exposure		
High (vs. low)	1.67	1.39–2.01
Moderate (vs. low)	1.23	1.05–1.44
Age (per 10 years)	1.21	1.13–1.29
Higher education level	0.88	0.84–0.92

†Adjusted for race, gender, smoking status, and work assignment.

CFI score in older participants after controlling for the mental health variables (OR: 1.45, 95% CI: 1.09–1.92). Current PTSD was associated with elevated CFI score in this age group (OR: 2.89, 95% CI: 2.06–4.07), as was early post-9/11 PTSD (OR: 1.71, 95% CI: 1.30–2.24).

Sensitivity analyses

In a sensitivity analysis, in which we defined elevated CFI score as top decile CFI score (≥5), high-level WTC exposure remained associated with an increased odds of elevated CFI score (OR vs. low-level exposure: 1.78, 95% CI: 1.37–2.31) when only demographic characteristics, work assignment, and smoking were included in the logistic model.

Table 4. Logistic regression analyses modeling associations of World Trade Center (WTC) exposure intensity and PTSD with elevated (top quartile) Cognitive Function Instrument score†

	Model A		Model B‡	
Variable	Odds ratio	95% Confidence interval	Odds ratio	95% Confidence interval
WTC exposure				
High (vs. low)	1.32	1.07–1.63	1.30	1.03–1.65
Moderate (vs. low)	1.13	0.94–1.35	1.12	0.91–1.36
Current PTSD	3.25	2.53–4.19		N/A
Early post-9/11 PTSD		N/A	1.56	1.26–1.93
Current depression	9.12	7.75–10.73	13.17	11.22–15.46
Current alcohol abuse	1.99	1.61–2.46	1.98	1.56–2.51
Age (per 10 years)	1.24	1.15–1.35	1.23	1.13–1.35
Higher education level	0.88	0.83–0.93	0.86	0.81–0.91

†Adjusted for race, gender, smoking status, and work assignment.
‡$N = 6440$.

When the mental health conditions were also included as covariates, the association between WTC exposure and elevated CFI score was attenuated and no longer statistically significant (OR: 1.19, 95% CI: 0.87–1.62). Both early post-9/11 and current PTSD were still associated with elevated CFI score (OR: 1.47, 95% CI: 1.12–1.92 and OR: 3.54, 95% CI: 2.83–4.43.).

A second sensitivity analysis used the adjusted CFI score, which excluded the question about social isolation. In this analysis, high-level WTC exposure increased the odds of having an adjusted CFI score in the top quartile (≥1.5) (OR: 1.56, 95% CI: 1.31–1.87); this association remained even after controlling for current PTSD, depression, and alcohol abuse (OR: 1.25, 95% CI: 1.02–1.52). The associations between PTSD and top-quartile CFI score were similar to those observed in our primary analyses.

Discussion

Our study is the first to investigate subjective cognitive concerns in FDNY firefighters and EMS who participated in the WTC rescue/recovery effort. High-intensity WTC exposure was predictive of self-reported cognitive change in the previous year in this population, even after controlling for PTSD, depression, and alcohol abuse. This finding is in line with the results of a recent study of cognitive function in non-FDNY WTC responders, which found that participants had worse cognitive function than would have been expected relative to age-matched clinical trial data (15). In that investigation, an objective measure of cognitive function was used. This previous study also found that responders who spent ≥ 5 weeks at the WTC site had an increased risk of cognitive dysfunction and that those with more PTSD symptoms were at the greatest risk (15). In our study, the association between WTC exposure level and elevated CFI score was attenuated after controlling for the mental health conditions of PTSD, depression, and alcohol abuse. Age-stratified analyses showed that while higher-level WTC exposure, PTSD, depression, and alcohol abuse were all significantly associated with elevated CFI score in older individuals (age> 55), higher WTC exposure did not predict elevated CFI score in younger participants (age 36–55) after controlling for the mental health conditions. In both age groups, early post-9/11 PTSD was associated with a modest increase in the odds of having an elevated CFI score 17 years later, and current PTSD and depression were both strongly associated with elevated CFI scores.

Approximately 8% of WTC-exposed FDNY workers reported increasing memory loss in the year prior to their 2018–2019 medical monitoring examination, which was lower than the 11% of US adults ≥ 45 in 2016 who reported experiencing increased confusion or memory loss in the past 12 months (4). In our population, this complaint was more prevalent in the subset of participants with high-intensity WTC exposure (11%) and was especially notable in those with concurrent PTSD and depression (38%). CFI items related to cognition received higher levels of endorsement than those related to functional difficulties. The most commonly reported concerns were memory-related, such as greater reliance on written reminders and more difficulty recalling names and words. More than half of the individuals who had both current PTSD and depression endorsed these CFI items. After controlling for potential confounders, we observed associations between current PTSD and depression and subjective cognitive concerns, as well as a longitudinal association between early post-9/11 PTSD and subjective cognitive concerns.

The version of the PCL that was used to assess current PTSD in our cohort was the PCL-S, which asked participants about symptoms related to a specific traumatic event that they had identified as their most traumatic experience. Eighty-four per cent of individuals with current PTSD indicated that WTC rescue/recovery work was their most traumatic, but not necessarily their only traumatic event, which suggests that current PTSD symptoms in this population remain largely linked to WTC exposure. We note, however, that 74% of those with current PTSD reported that they had experienced more than one traumatic event, possibly due to their work as firefighters and/or EMS

workers. These data raise the possibility that PTSD symptoms in FDNY WTC rescue/recovery workers result from experiencing multiple traumatic exposures. This type of PTSD has been associated with increased symptom severity and worse outcomes when compared with single-incident PTSD (32, 33).

Many previous studies of PTSD and cognitive function were carried out in populations of military veterans (16, 34, 35); however, a connection between PTSD and cognitive impairment has also been observed in studies of individuals exposed to other types of trauma (12, 13, 36), as well as in one study involving a general population (14). In the previously noted cohort of non-FDNY WTC responders, PTSD symptoms were associated with an increased risk of cognitive impairment (15). Responders with PTSD had worse performance on the online neuropsychological battery Cogstate across multiple cognitive domains, including memory. PTSD was also linked to worse learning/working memory and psychomotor speed in a cohort of non-WTC-exposed civilians who completed the same neuropsychological battery (14).

The CFI is a subjective cognitive measure that was previously validated in an older civilian population (20, 22). In cross-sectional analyses, CFI scores have been associated with cognitive impairment and/or worse cognition (20, 37, 38). In longitudinal studies, baseline CFI scores and change in CFI scores over time predicted cognitive decline (20, 30, 31). We chose to use the CFI due to its brevity and ease of administration. While our results suggest a connection between PTSD, both past and current, and worsening cognition in FDNY WTC-exposed rescue/recovery workers, further research using an objective cognitive assessment will be needed to confirm this association. Our use of self-report data means that this study was vulnerable to state-dependent bias: individuals with current PTSD and/or depressive symptoms may be more concerned about their cognitive function, and therefore more likely to endorse CFI items, compared to those who are not experiencing these symptoms. Use of an objective cognitive assessment in future studies will allow us to determine whether there are observable differences in objective cognition between the aforementioned groups.

A second study limitation was our use of the PCL-m to assess individuals' PTSD symptoms at baseline, as this measure was not externally validated; however, we found high agreement between the PCL-m and the PCL in our population (24). We also did not have information on individuals' baseline cognitive status, as no cognitive assessment was performed in this population before 3/1/2018. However, because participants were 17 years younger and part of a healthy occupational cohort on 9/11, it is reasonable to expect that most were cognitively normal at baseline.

It is important to note that certain CFI items are similar to items on the PCL and the CES-D. Specifically, there is a question about social isolation on all three questionnaires. We addressed this concern of overlap by performing a sensitivity analysis that excluded the social isolation question from individuals' CFI scores, and finding similar results to our primary analyses. The PCL also has a question having to do with memory problems; however, this question differs from memory questions on the CFI in that it is specific to loss of memories of the traumatic event(s).

We observed a high level of comorbidity between current PTSD and current depression: the vast majority (92%) of participants with current PTSD had concurrent depression. Studies have consistently shown depression to be associated with cognitive impairment and dementia (9, 10, 39, 40). In our analyses, depression was the variable associated with the greatest increase in the odds of subjective cognitive concerns: individuals with current depression were over nine times more likely to have an elevated CFI score than those without current depression. Since there were relatively few individuals ($N = 54$) with current PTSD who did *not* have current depression in our study cohort, we did not conduct our primary analyses in this subpopulation, and instead controlled for depression in our analyses to determine if PTSD and elevated CFI scores were independently associated.

Selection bias was a concern in this study because only 69% of FDNY rescue/recovery workers had a medical monitoring examination after the CFI was incorporated into the FDNY mental health questionnaire. The rescue/recovery workers who participated in the study were similar to the source population in age and education level. While individuals who are experiencing cognitive and/or mental health problems may be less likely to attend FDNY health monitoring exams than those without these problems, not being seen in any 12-month interval is typically the result of normal scheduling delays rather than disease.

Finally, while we found that high-intensity WTC exposure was modestly associated with subjective cognitive concerns 17 years later, we believe that the observed effect may be due to the high prevalence of WTC exposure-related illnesses among the most exposed. Several chronic physical health illnesses, ranging from acid reflux to asthma, have been linked to greater WTC exposure (17) and

some of these illnesses or their treatments could be risk factors for cognitive impairment (41) in WTC rescue/recovery workers. Future research examining risk factors for cognitive impairment in WTC-exposed rescue/recovery workers should evaluate the association between WTC-related health conditions and cognitive function using mediation analyses. The identification of certain WTC-related illnesses as risk factors for cognitive impairment will highlight groups that may benefit from additional cognitive diagnostic evaluations and interventions.

Study strengths include the use of a subjective cognitive measure that is sensitive to early-stage cognitive impairment, as well as the use of different cut-points to determine which CFI scores were classified as elevated in our analyses. Another study strength was the availability of a wide range of data for this study population, including information on several potential confounders, via the FDNY WTC Health Program.

In summary, rescue/recovery workers who had high-intensity WTC exposure, and those who have or had PTSD, have an elevated risk of self-reported cognitive concerns. Self-perceived decline in cognitive functioning may be associated with increased cognitive decline and dementia (5). Not surprisingly, our results indicate that other mental health conditions, particularly depression and alcohol abuse, are also risk factors for self-reported cognitive concerns in this population. Identification of high-risk subgroups within the WTC rescue/recovery worker population will facilitate early detection of cognitive impairment via objective cognitive battery, and therefore allow for early intervention and disease monitoring.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author, in accordance with the FDNY WTC Health Program data sharing agreement. The data are not publicly available due to privacy or ethical restrictions.

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