Probable Posttraumatic Stress Disorder and Lower Respiratory Symptoms Among Rescue/Recovery Workers and Community Members After the 9/11 World Trade Center Attacks—A Longitudinal Mediation Analysis

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ABSTRACT

Objective: Posttraumatic stress disorder (PTSD) and lower respiratory symptoms (LRS) often coexist among survivors of the September 11, 2001 (9/11) World Trade Center (WTC) attacks. Research in police and nontraditional responders suggests that PTSD mediates the relationship between 9/11 physical exposures and LRS, but not vice versa. We replicated these findings in WTC rescue/recovery workers (R/R workers), extended them to exposed community members, and explored the interplay between both physical and psychological 9/11 exposures, probable PTSD, and LRS over a 10-year follow-up.

Methods: Participants were 12,398 R/R workers and 12,745 community members assessed in three WTC Health Registry surveys (2003–2004, 2006–2007, and 2011–2012). LRS and 9/11 exposures were self-reported. Probable PTSD was defined as a PTSD Checklist score ≥44.

Results: Probable PTSD predicted LRS (R/R workers: $\beta = 0.88–0.98$, $p < .001$; community members: $\beta = 0.67–0.86$, $p < .001$) and LRS predicted PTSD (R/R workers: $\beta = 0.83–0.91$, $p < .001$; community members: $\beta = 0.68–0.75$, $p < .001$) at follow-ups, adjusting for prior symptoms and covariates. In both R/R workers and community members, probable PTSD mediated the relationship between 9/11 physical exposures (dust cloud, long duration of work) and LRS (indirect effects, $p = .001–.006$), and LRS mediated the physical exposure-PTSD relationship (indirect effects, $p = .001–.006$). In R/R workers, probable PTSD mediated the psychological exposure (losing friends or loved ones, witnessing horrific events)–LRS relationship (indirect effect, $p < .001$), but LRS did not mediate the psychological exposure-PTSD relationship (indirect effect, $p = .332$). In community members, high 9/11 psychological exposure predicted both probable PTSD and LRS at follow-ups; probable PTSD mediated the psychological exposure-LRS relationship (indirect effect, $p < .001$), and LRS mediated the psychological exposure-PTSD relationship (indirect effect, $p = .001$).

Conclusions: Probable PTSD and LRS each mediated the other, with subtle differences between R/R workers and community members. A diagnosis of either should trigger assessment for the other; treatment should be carefully coordinated.

Key words: PTSD, lower respiratory symptoms, 9/11 disaster, occupational medicine.

INTRODUCTION

Posttraumatic stress disorder (PTSD) and lower respiratory illnesses are two of the most common chronic health conditions among individuals exposed to the 9/11 World Trade Center (WTC) terrorist attacks (1–3). Given the relatively high prevalence of PTSD and lower respiratory symptoms (LRS) in this population and the extensive overlap in 9/11-related exposures associated with each condition, it is not surprising that PTSD and LRS often co-occur. Among adult enrollees in the WTC Health Registry (WTCHR) 5 to 6 years after the disaster, comorbid PTSD and LRS were found in 9.8% of WTC rescue/recovery responders (4) and 5.8% of community members (5). Approximately 38% of adult enrollees who reported persistent LRS 10 years after the disaster also reported having symptoms consistent with PTSD (6).

It has been noted that PTSD and LRS coexist more frequently than would be expected if the two conditions were independent (3,4), and that individuals with both conditions report more severe and persistent PTSD and LRS than do individuals with either condition alone (5–7), suggesting a complex interplay between PTSD and LRS in this population. One set of hypotheses suggests that PTSD may produce pulmonary inflammation and respiratory symptoms through increased sympathetic activity (8) and immune system dysregulation (9,10). Chronic respiratory symptoms may

BMI = body mass index, **LRS** = lower respiratory symptoms, **PTSD** = posttraumatic stress disorder, **R/R workers** = rescue/recovery workers, **WTC** = World Trade Center, **WTCHR** = World Trade Center Health Registry

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contribute to the development and maintenance of PTSD through recurrent reminders of the trauma, which may trigger PTSD symptoms, or by interfering with PTSD care through impaired daily functioning (11–13). Epigenetic linkages between PTSD and respiratory illness are currently under study (14–16).

Despite the observed link between PTSD and LRS, the mechanisms underlying this phenomenon are unclear. In one study, using structural equation modeling, Luft et al. (12) found that probable PTSD statistically partially mediated the relationship between 9/11 exposure and LRS in rescue/recovery workers (R/R workers; police and nontraditional responders), supporting the hypothesis that physiological or immunologic dysregulation associated with PTSD may contribute to LRS in these populations. However, this analysis was cross sectional, limiting causal inference. In a follow-up study, Kotov et al. (13) provided further evidence for the proposed model using two-wave longitudinal data; probable PTSD was found to partially mediate the association between 9/11 exposures and subsequent LRS, but not vice versa. Furthermore, probable PTSD predicted more onset and fewer remissions of LRS between baseline assessments in 2002 and follow-up assessments approximately 8 years later. However, the models did not include WTC-exposed community members, whose 9/11-related exposures and predisaster experiences were markedly different from those of WTC R/R workers and therefore may have a distinct relationship among WTC-related exposures, PTSD, and respiratory symptoms.

In the current study, we sought to replicate the aforementioned findings in WTC R/R workers in a different cohort, the WTCHR, and to describe the longitudinal relationship between probable PTSD and LRS among WTC-exposed community members. We also explored the role of a range of both physical and psychological 9/11 exposures on this relationship. We hypothesized that, in both R/R workers and community members, probable PTSD and LRS are interrelated and that intermediary probable PTSD and LRS each mediate the longitudinal relationships between 9/11 exposures and the other.

METHODS

Sample

Participants were WTCHR enrollees assessed over a 10-year period (three surveys). The Registry is a voluntary cohort of 71,434 R/R workers, lower Manhattan area residents and workers, and commuters and passersby on 9/11 that follows the long-term physical and mental health of enrollees via periodic questionnaires. Detailed information on the WTCHR and pre-9/11 general health of enrollees is available elsewhere (1,3,6,17,18). Wave 1 survey data were collected in 2003 to 2004, wave 2 in 2006 to 2007, and wave 3 in 2011 to 2012.

WTCHR enrollees included in the current study comprised 25,143 adults (18 years or older at enrollment/wave 1) with complete data on probable PTSD and LRS at each wave who did not report pre-9/11 LRS at wave 1. Pre-9/11 PTSD, first assessed at wave 2, was rare among WTCHR enrollees (prevalence estimates of approximately 0.1%) (1), suggesting that most PTSD identified at wave 1 resulted from 9/11 exposure (18). The sample included 12,398 WTC R/R workers (police, firefighters, emergency medical technicians, and sanitation workers, as well as volunteers) and 12,745 exposed community members (area workers, residents, and passersby). Group membership criteria (R/R workers or community member) were outlined in previous WTCHR studies (e.g., Refs. (1,3)). In summary, groups were mutually exclusive, with participants who had performed any rescue/recovery work classified as R/R workers and those who performed no rescue/recovery work classified as community members. Because those R/R and community members differed in terms of demographic composition and the extent of 9/11 exposure (Table 1), they were analyzed separately. Exclusion criteria were as follows: <18 years old at enrollment (2762), LRS before 9/11 (7945), no wave 2 and/or wave 3 surveys (28,827), completing all three surveys but missing data on probable PTSD (2864) or LRS (3847), and withdrawal from the Registry by the time of the analysis (46). Fifty-six percent of R/R workers and 50% of exposed community members completed all three waves of surveys; overall, these enrollees were slightly older, and more likely to be male (R/R workers only), non-Hispanic white, married, and with college degree or higher, compared with those who did not participate in all three surveys. The prevalence of LRS at wave 1 was similar in the two groups; however, the prevalence of probable WTC-related PTSD at enrollment was higher in those who did not participate in all three surveys than among those who did.

The Registry protocol and use of data for research purposes were approved by the New York City Department of Health and Mental Hygiene and City University of New York Graduate School of Public Health and Health Policy Institutional Review Boards.

Measures

The primary outcomes were probable PTSD and LRS. Probable PTSD was assessed using the PTSD Checklist (PCL) (19), which measures the severity of the 17 PTSD symptoms delineated by the *Diagnostic and Statistical Manual of Mental Disorders* (Fourth Edition). The questions were specific to WTC exposures and asked enrollees to rate their symptoms in the past 30 days on a scale from 1 (not at all) to 5 (extremely). The PCL has excellent psychometric properties and is a widely accepted self-reported measure of PTSD (20). In this study, probable PTSD was defined as a score ≥44. This cutoff was chosen because it showed a high concordance with the PCL-based PTSD diagnosis among civilians, defined based on the *Diagnostic and Statistical Manual of Mental Disorders* (Fourth Edition) criteria (i.e., at least moderate severity of symptoms and meeting a minimum of one reexperiencing symptom, at least two avoidance/numbing symptoms, and at least 3 hyperarousal symptoms; sensitivity, 0.94; specificity, 0.86; diagnostic efficiency, 0.90) (21).

LRSs were self-reported at each survey. At wave 1, LRSs were new cough, wheezing, and/or shortness of breath since 9/11. At wave 2 and wave 3, the same LRS definition was used, with symptoms reported in the 30 days before the interview. In addition, at wave 3, participants were explicitly asked to report symptoms not occurring during a flu or cold.

WTC exposures considered in this analysis were grouped into physical and psychological categories. Physical exposure for R/R workers included experiencing the dust/debris cloud on 9/11 (heavy or intermediate versus not), long duration of work (>50 days; yes versus no), and working on the pile of rubble resulting from the collapse of the WTC buildings and surrounding infrastructure (yes versus no). In community members, exposures included dust cloud contact on 9/11 (heavy or intermediate versus not), evacuation from the home/workplace due to WTC disaster (yes versus no), or encountering a heavy layer of dust in the home/workplace upon return after WTC disaster (yes versus no). Psychological exposure was defined for both groups as having witnessed a horrific event in person, having feared for one's life during the attacks, or having a relative, friend/acquaintance, or coworker injured/killed during the attacks. Participants who reported experiencing at least three of these five events were considered to have high psychological exposure, and those who reported two or fewer were categorized as low psychological exposure. This characterization of high psychological exposure was developed based on the definitions by Adams et al. (22) and Brackbill et al. (23), where overall WTC exposure, based on 14 possible events, was classified as none/low (0–1 experiences), medium (2–3 experiences), high (4–5 experiences), and very high (≥6 experiences). High psychological exposure (at least three events) showed a clear dose-response relationship with the study outcomes (probable PTSD, LRS; data not shown). All exposure variables were assessed at

TABLE 1. Demographic and 9/11 Exposure Profiles of R/R Workers and Community Members

Characteristic	R/R Workers (n = 12,398)	Community Members (n = 12,745)	p	Standardized Difference[a]
Age on 9/11, >42 y	45.1	48.5	<.001	−0.07
Sex, female	20.8	52.8	<.001	**−0.81**
Race/ethnicity, white	80.3	68.7	<.001	0.16
Education, college or higher	44.4	68.3	<.001	**−0.42**
Relationship status, married/cohabiting	74	61.2	<.001	0.19
Dust cloud exposure on 9/11	38.2	63.8	<.001	**−0.49**
Long duration of work (>50 d)	24.6	—	—	—
Work on pile	47.2	—	—	—
Evacuated home/workplace	—	80.9	—	—
Heavy dust in home/workplace	—	11.9	—	—
High psychological exposure	24.3	28.9	<.001	−0.18
Pre-9/11 psychological trauma	46.9	33.6	<.001	**0.33**
Pre-9/11 mental health history	7.4	11.7	<.001	**−0.46**
Injuries on 9/11	15.6	11.2	<.001	**0.34**
Current smoker wave 1	14.1	13.2	0.05	0.07
Current smoker wave 2	13.1	12.0	0.003	0.09
Current smoker wave 3	10.3	9.3	0.012	0.11
BMI obese wave 3	37.3	25.5	<.001	**0.38**
Years from 9/11 wave 1, M (SD)	2.76 (0.42)	2.65 (0.48)	<.001	**0.24**
Years from 9/11 wave 21, M (SD)	5.59 (0.49)	5.58 (0.50)	0.011	0.02
Years from 9/11 wave 31, M (SD)	10.06 (0.26)	10.08 (0.27)	0.059	−0.08

R/R workers = rescue/recovery workers; M = mean; BMI = body mass index.

Vales are presented in percent, unless otherwise indicated.

[a] Standardized difference is the difference in proportions or means divided by SE; group imbalance (shown in bold) corresponds to a standardized difference that is greater than or equal to a small effect size of 0.20.

wave 1 survey. Intensity of dust cloud exposure was further clarified at wave 2. All exposures included in this analysis have been documented to predict probable PTSD and/or LRS (1,2,12).

Demographic characteristics included age at 9/11/2001 (>42 years [the median age versus not]), sex (female versus male), race/ethnicity (white versus other), education at wave 1 (college or higher versus other), and relationship status at wave 1 (married/cohabiting versus other). Other covariates included pre-9/11 psychological trauma (yes versus no), pre-9/11 mental health history (diagnosis of PTSD, depression, and/or anxiety; yes versus no), 9/11-related injury (a burn, broken bone, concussion, cut, sprain, or strain on 9/11), body mass index (BMI) status at wave 3 (obese versus other), and smoking status at each wave (current smoker versus nonsmoker). These covariates were adjusted for in all models because they have been shown to predict PTSD and/or LRS (4–6).

Statistical Analyses

We stratified all analyses on whether participants were R/R workers or community members. Descriptive statistics and χ^2 tests were used to describe demographic characteristics, 9/11 exposures, and rates of probable PTSD and LRS in both samples.

To glean information on the stability and co-occurrence between probable PTSD and LRS as well as their unadjusted longitudinal associations with 9/11 physical and psychological exposures, we computed a set of tetrachoric correlations over time (autoregressive, contemporaneous, and cross-lagged correlations). Correlations of $r \geq 0.20$ were considered to indicate moderate associations (24).

Adjusted three-wave path models (25,26) were used to assess longitudinal relationships among 9/11 physical and psychological exposures and study outcomes (LRS and probable PTSD at wave 1, wave 2, and wave 3). The models included all autoregressive effects (probable $PTSD_{Wave\ i}$ → probable $PTSD_{Wave\ i+1}$ and $LRS_{Wave\ i}$ → $LRS_{Wave\ i+1}$) and cross-lagged effects (probable $PTSD_{Wave\ i}$ → $LRS_{Wave\ i+1}$ and $LRS_{Wave\ i}$ → probable $PTSD_{Wave\ i+1}$). Mediation hypotheses were tested by assessing the statistical significance ($p < .01$) and the difference in magnitude (contrasts) of selected indirect effects (27,28). Specifically, we tested whether a potential mediator, measured at wave 2, mediated the relationship between 9/11-related exposures and the outcome measured at wave 3 (9/11 exposure → probable $PTSD_{Wave\ 2}$ → $LRS_{Wave\ 3}$ and 9/11 exposure → $LRS_{Wave\ 2}$ → probable $PTSD_{Wave\ 3}$), adjusting for wave 1 outcomes.

All analyses were adjusted for demographic variables (age, sex, race/ethnicity, education, relationship status), time in years since the WTC attacks at the completion of each wave, 9/11-related injuries, pre-9/11 psychological trauma and pre-9/11 mental health history, BMI at wave 3, and current smoking at each wave. Because multiple statistical tests were performed, we considered a maximum p value of .01 statistically significant. Analyses were performed in Mplus (version 7) (29) and SAS (version 9.2) (30).

RESULTS

Demographic and 9/11 Exposure Profiles

R/R workers and community members differed with respect to most demographic characteristics and 9/11 exposures (Table 1). As compared with community members, R/R workers were less likely to be female (20.8% versus 52.8%), older than 42 years on

9/11/2001 (45.1% versus 48.5%), and college educated (44.4% versus 68.3%); however, they were more likely to be white (80.3% versus 68.7%) and married or cohabiting (74.0% versus 61.2%). R/R workers reported more pre-9/11 trauma (46.9% versus 33.6%) but less pre-9/11 mental health diagnoses (7.4% versus 11.7%). They were slightly more likely to be smokers and reported higher BMI at wave 3.

Approximately half of R/R workers labored on the pile (47.2%), and approximately a quarter (24.6%) reported a long duration of work (>50 days). Dust cloud exposure was reported by 38.2% of workers. In contrast, 63.8% of community members reported being exposed to the dust cloud, whereas 80.9% evacuated from home or workplace and 11.9% reported heavy dust in the home or workplace. Finally, community members reported significantly more high psychological exposure (28.9% versus 24.3%, $p < .001$).

Probable PTSD and LRS Over Time

Probable PTSD and LRS over time are described in Table 2. Relative to wave 1, probable PTSD rates increased by wave 2 and then decreased by wave 3. In contrast, LRS rates decreased sharply by wave 2 and slightly thereafter. These trends were observed in both R/R workers and community members. Probable PTSD-LRS comorbidity rates at wave 1, wave 2, and wave 3 were 9.5%, 14.1%, and 13.2% in R/R workers and 11.4%, 11.9%, and 10% in community members. Remission rates by wave 3 were higher in community members (43.5% for probable PTSD and 50.1% for LRS) than in R/R workers (35.3% for probable PTSD and 40.6% for LRS), but relatively low in both groups, indicating a high level of chronicity. At wave 3, there were approximately 5570 chronic LRS cases (60% in R/R workers and 40% in community members) and approximately 1600 probable PTSD chronic cases (45% in R/R workers and 55% in community members). Approximately 2450 LRS cases (50% in R/R workers and 50% in community members) and approximately 2075 probable PTSD cases (58% in R/R workers and 42% in community members) were first reported at wave 2 or wave 3.

Unadjusted Associations of 9/11 Exposures, Probable PTSD, and LRS

Probable PTSD and LRS rates were relatively stable over time in R/R workers (autoregressive correlations, $r = 0.77–0.81$ for probable PTSD and $r = 0.60–0.64$ for LRS) and in community members ($r = 0.79–0.81$ for probable PTSD and $r = 0.58–0.61$ for

TABLE 2. Probable PTSD and LRS Over Time

Characteristic	R/R Workers (n = 12,398), %	Community Members (n = 12,745), %	p	Standardized Difference[a]
LRS wave 1	57.4	47.6	<.001	0.19
LRS wave 2	47.0	35.6	<.001	**0.28**
LRS wave 3	44.0	33.0	<.001	**0.29**
LRS course			—	
Chronic	27.2	17.3		
Remitted wave 2	13.6	15.2		
Remitted wave 3	9.8	8.8		
New onset wave 2	4.4	3.7		
New onset wave 3	5.5	5.8		
Fluctuating[a]	12.3	12.1		
No LRS	27.0	37.1		
Probable PTSD wave 1	10.6	14.6	<.001	**−0.33**
Probable PTSD wave 2	18.2	17.9	.559	0.02
Probable PTSD wave 3	16.7	15.0	<.001	0.11
Probable PTSD course			—	
Chronic	5.8	6.9		
Remitted wave 2	1.9	3.7		
Remitted wave 3	1.8	2.6		
New onset wave 2	5.2	3.4		
New onset wave 3	4.6	3.4		
Fluctuating*	6.4	6.2		
No probable PTSD	74.2	73.7		
LRS and probable PTSD wave 1	9.5	11.4	<.001	
LRS and probable PTSD wave 2	14.1	11.9	<.001	
LRS and probable PTSD wave 3	13.2	10.0	<.001	

PTSD = posttraumatic stress disorder; LRS = lower respiratory symptoms; R/R workers = rescue/recovery workers.

[a]Fluctuating course includes conditions present at 1) wave 1 and wave 3 but not wave 2, and 2) wave 2 but not wave 1 and wave 3. Standardized difference is the difference in proportions or means divided by SE; group imbalance (small effect size corresponding to a standardized difference ≥0.20) are shown in bold.

TABLE 3. Tetrachoric Correlation Between 9/11 Exposures, Probable PTSD, and LRS Over Time

	RRW (n = 12,398)						Community Members (n = 12,745)					
	LRS Wave 1	LRS Wave 2	LRS Wave 3	PTSD Wave 1	PTSD Wave 2	PTSD Wave 3	LRS Wave 1	LRS Wave 2	LRS Wave 3	PTSD Wave 1	PTSD Wave 2	PTSD Wave 3
Dust cloud exposure on 9/11	**0.38**	**0.26**	0.19	**0.27**	**0.28**	**0.26**	**0.29**	**0.22**	**0.21**	**0.29**	**0.26**	**0.26**
Long duration of work (>50 d)	**0.30**	**0.23**	0.17	0.19	**0.20**	0.18	—	—	—	—	—	—
Work on pile	**0.34**	**0.21**	0.15	0.02	0.14	0.11	—	—	—	—	—	—
Evacuate home/workplace	—	—	—	—	—	—	−0.04	−0.06	−0.03	−0.02	0.00	0.03
Heave dust home/workplace	—	—	—	—	—	—	**0.22**	**0.20**	0.18	0.19	**0.25**	**0.20**
High psychological exposure	**0.42**	**0.27**	**0.21**	**0.32**	**0.37**	**0.30**	0.18	0.18	**0.22**	**0.34**	**0.39**	**0.39**
LRS wave 1		**0.60**	**0.55**	**0.52**	**0.50**	**0.47**		**0.58**	**0.52**	**0.49**	**0.46**	**0.42**
LRS wave 2			**0.64**	**0.46**	**0.52**	**0.48**			**0.61**	**0.43**	**0.51**	**0.47**
LRS wave 3				**0.44**	**0.48**	**0.57**				**0.44**	**0.49**	**0.53**
Probable PTSD wave 1					**0.77**	**0.73**					**0.79**	**0.75**
Probable PTSD wave 2						**0.81**						**0.81**

PTSD = posttraumatic stress disorder; LRS = lower respiratory symptoms; RRW = rescue/recovery workers.
Moderate associations ($r \geq 0.20$) are shown in bold.

LRS; Table 3). In both groups, concurrent probable PTSD-LRS associations were also substantial (contemporaneous correlations, r = 0.49–0.57). Longitudinal associations between initial LRS and subsequent probable PTSD and initial probable PTSD and subsequent LRS were substantial in both R/R workers (cross-lagged correlations, r = 0.47–0.50 and r = 0.44–0.46, respectively) and in community members (r = 0.42–0.46 and r = 0.43–0.44, respectively).

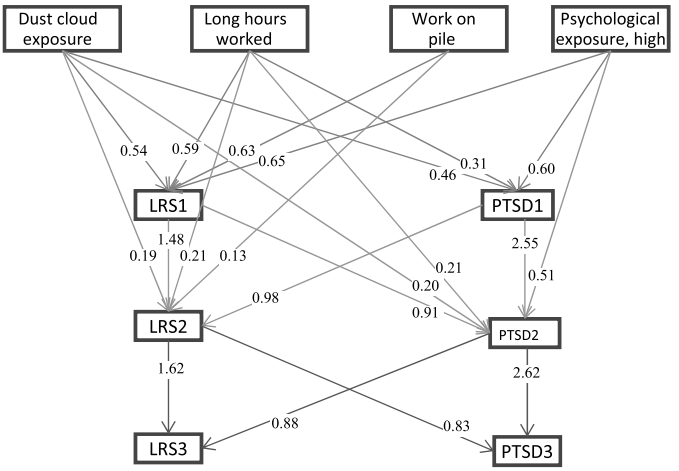
Most physical and psychological 9/11 exposures showed moderate associations with both probable PTSD and LRS over time. The strongest correlations were observed at wave 1; these correlations generally decreased over time for LRS but stayed relatively stable for probable PTSD (Table 3). Dust cloud exposure and high psychological exposure showed consistently stronger correlations with probable PTSD and LRS compared with other exposures (r = 0.19–0.42 in R/R workers and r = 0.18–0.39 in community members). In R/R workers, both exposures were more strongly associated with LRS than with probable PTSD at wave 1; in contrast, these exposures were more strongly associated with probable PTSD than with LRS at wave 2 and wave 3. In community members, high psychological exposure was consistently highly correlated with probable PTSD (r = 0.34–0.39), but not LRS (r = 0.18–0.22). Finally, long hours worked was moderately associated with LRS and probable PTSD over time (r = 0.17–0.30); working on the pile showed moderate association with LRS (r = 0.15–0.34) but only a weak association with probable PTSD over time (r = 0.02–0.14). Exposure to a heavy layer of dust in the home/workplace upon return after the WTC disaster was moderately associated with both LRS (r = 0.18–0.22) and probable PTSD (r = 0.19–0.25); in contrast, WTC-related evacuation from the home or workplace was not associated with either condition (r = −0.06 to 0.03).

Adjusted Longitudinal Path Models and Mediation Analyses

In the adjusted three-wave path analyses (Figures 1A, B), estimated autoregressive predictive effects for both probable PTSD and LRS over time were substantial and similar in R/R workers and community members (probable $PTSD_{Wave\ i} \rightarrow$ probable $PTSD_{Wave\ i+1}$: β = 2.55–2.62 for R/R workers and β = 2.44–2.65 for community members; $LRS_{Wave\ i} \rightarrow LRS_{Wave\ i+1}$: β = 1.48–1.62 for R/R workers and β = 1.46–1.53 for community members; $p < .001$). Cross-lagged paths (probable $PTSD_{Wave\ i} \rightarrow LRS_{Wave\ i+1}$, $LRS_{Wave\ i} \rightarrow$ probable $PTSD_{Wave\ i+1}$) were positive and statistically significant ($p < .001$), showing that LRS predicted subsequent probable PTSD, and probable PTSD predicted subsequent LRS, adjusting for autocorrelations and covariates. The magnitude of the effects suggest that these relationships are similar within groups (for R/R workers [Figure 1A], $LRS_{Wave\ i} \rightarrow$ probable $PTSD_{Wave\ i+1}$: β = 0.83–0.91, probable $PTSD_{Wave\ i} \rightarrow LRS_{Wave\ i+1}$: β = 0.88–0.98; for community members [Figure 1B], $LRS_{Wave\ i} \rightarrow$ probable $PTSD_{Wave\ i+1}$: β = 0.68–0.75, probable $PTSD_{Wave\ i} \rightarrow LRS_{Wave\ i+1}$: β = 0.67–0.86).

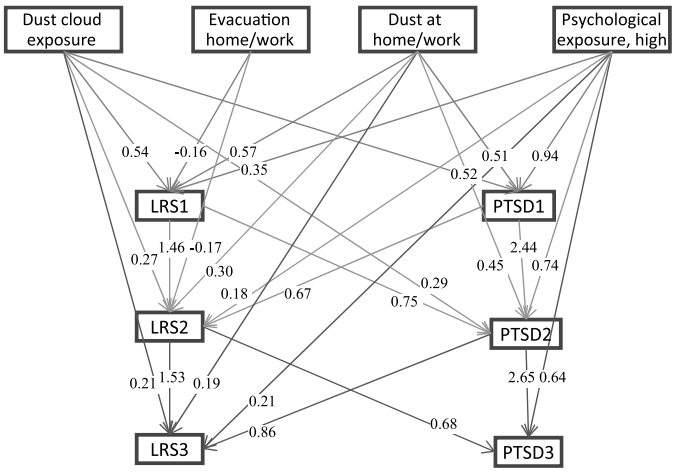
In R/R workers, Figure 1A, both physical and psychological 9/11 exposures, except working on the pile, were associated with probable PTSD at wave 1 and wave 2 ($p < .001$). Dust cloud exposure and high psychological exposure were only marginally associated with probable PTSD at wave 3 (p = .016 and p = .056, respectively). In contrast, all 9/11 exposures were associated with LRS

A R/R workers



Only significant paths ($p < .01$) are shown. Marginally significant paths at Wave 3 for 1) LRS: dust cloud exposure ($\beta = 0.136$, $p = .016$), long duration of work ($\beta = 0.133$, $p = .033$, work on pile ($\beta = 0.105$, $p = .035$); 2) probable PTSD: dust cloud exposure ($\beta = .200$, $p = .012$), high psychological exposure ($\beta = 0.162$, $p = .056$). LRS1-3 is lower respiratory symptoms at Wave 1, 2 and 3; PTSD1-3 is probable post-traumatic stress disorder at Waves 1, 2 and 3.

B Community members



Only significant paths ($p < .01$) are shown. Marginally significant paths at Wave 3 for 1) LRS: none were marginally significant; 2) probable PTSD: dust cloud exposure ($\beta = 0.176$, $p = .022$). LRS1-3 is lower respiratory symptoms at Wave 1, 2 and 3; PTSD1-3 is probable post-traumatic stress disorder at Waves 1, 2 and 3.

FIGURE 1. Adjusted three-wave longitudinal path models. R/R workers = rescue/recovery workers; LRS = lower respiratory symptoms; PTSD = posttraumatic stress disorder. Color image is available only in the online version (www.psychosomaticmedicine.org).

at wave 1 ($p < .001$). LRSs at wave 2 were predicted by physical exposures only ($p < .001$); these effects were only marginally significant at wave 3 (all, $p < .01$).

Mediation analyses for R/R workers (Table 4) showed that probable PTSD at wave 2 mediated the relationship between 9/11 physical exposures (dust cloud, long duration of work) and LRS at wave 3 (indirect effect, $p = .006$ and $p = .001$, respectively), and LRS at wave 2 mediated the physical exposures–probable PTSD relationship (indirect effect, $p = .004$ and $p < .001$, respectively). There were no statistically significant differences in the magnitude of these indirect effects (contrast, $p = .814$ and $p = .876$, respectively). Probable PTSD also mediated the relationship between psychological exposures and subsequent LRS (indirect effect, $p < .001$); however, LRS did not mediate the relationship between psychological exposures and probable PTSD (indirect effect, $p = .332$).

Findings were similar in community members. In Figure 1A, exposures to the dust cloud and to a heavy layer of dust at home/

TABLE 4. Mediation Analysis: Indirect Effects

	Indirect Effect	SE	*p*
R/R workers (*n* = 12,398)			
1a. Dust cloud exposure–LRS3 via PTSD2	0.177	0.065	.006
1b. Dust cloud exposure–PTSD3 via LRS2	0.159	0.047	.001
Contrast: 1a–1b	0.017	0.074	.814
2a. Long duration of work–LRS3 via PTSD2	0.181	0.062	.004
2b. Long duration of work–PTSD3 via LRS2	0.170	0.046	<.001
Contrast: 2a–2b	0.011	0.072	.876
3a. Worked on pile–LRS3 via PTSD2	0.110	0.063	.080
3b. Worked on pile–PTSD3 via LRS2	0.105	0.042	.012
Contrast: 3a–3b	0.005	0.070	0.945
4a. High psychological exposure–-LRS3 via PTSD2	0.446	0.073	<.001
4b. High psychological exposure–PTSD3 via LRS2	0.049	0.050	.332
Contrast: 4a–4b	**0.397**	**0.083**	**<.001**
Community members (*n* = 12,745)			
1a. Dust cloud exposure–LRS3 via PTSD2	0.251	0.061	<.001
1b. Dust cloud exposure–PTSD3 via LRS2	0.184	0.038	<.001
Contrast: 1a–1b	0.067	0.068	.327
2a. Evacuate home/work–LRS3 via PTSD2	−0.015	0.072	.838
2b. Evacuate home/work–PTSD3 via LRS2	−0.113	0.041	.006
Contrast: 2a–2b	0.098	0.078	.208
3a. Dust at home/work–LRS3 via PTSD2	0.385	0.080	<.001
3b. Dust at home/work–PTSD3 via LRS2	0.202	0.051	<.001
Contrast: 3a–3b	0.183	0.089	.040
4a. Psychological exposure–LRS3 via PTSD2	0.636	0.073	<.001
4b. Psychological exposure–PTSD3 via LRS2	0.120	0.037	.001
Contrast: 4a–4b	**0.516**	**0.078**	**<.001**

R/R workers = rescue/recovery workers; LRS = lower respiratory symptoms; PTSD = posttraumatic stress disorder.

Statistically significant effects are bolded. LRS1–3 is LRS at waves 1, 2, and 3; PTSD1–3 is probable PTSD at waves 1, 2, and 3.

workplace were predictive of probable PTSD at waves 1 and 2 (all, $p < .001$), and dust cloud exposure showed a marginal association with probable PTSD at wave 3 ($p = .022$). High psychological exposure consistently predicted probable PTSD over time ($p < .001$). Finally, both physical and psychological 9/11 exposures predicted LRS at wave 1, wave 2, and wave 3, with the exception of evacuation from the home/workplace and LRS at wave 3. Of note, the estimated paths for this exposure were negative, suggesting a protective effect of evacuation on LRS at waves 1 and 2. Mediation analyses (Table 4) showed significant indirect effects for dust cloud exposure and dust exposure at home/workplace and LRS at wave 3 via probable PTSD at wave 2, and vice versa ($p < .001$). Furthermore, LRS at wave 2 mediated the evacuation from home/work–probable PTSD relationship (indirect effect, $p = .006$), but not vice versa (indirect effect, $p = .838$). Finally, probable PTSD at wave 2 mediated the psychological exposure–LRS at wave 3 relationship and vice versa; however, the former effect was stronger (β difference = 0.516, $p < .001$).

DISCUSSION

We studied the interplay among 9/11-related exposures, probable PTSD, and LRS over a 10-year period (2003–2012). We found that more than one-tenth of R/R workers and exposed community members reported chronic comorbid probable PTSD and LRS throughout this follow-up period. Relative size of the autoregressive β coefficients indicated probable PTSD was more stable compared with LRS, however relative size of the cross-lagged β coefficients showed a similar strength of the longitudinal probable PTSD–LRS relationship. Furthermore, probable PTSD and LRS each mediated the relationship between 9/11-related exposures and the other health outcome. Among R/R workers, probable PTSD mediated the relationship between both physical and psychological exposures and persistent LRS, and LRS mediated the relationship physical exposures and chronic probable PTSD. These pathways were also significant in 9/11-exposed community members; in addition, LRS mediated the relationship between psychological exposures and probable PTSD in this group.

Previous studies of a cohort of 9/11-exposed police and nontraditional recue/recovery workers found that probable PTSD was an independent risk factor for the development and persistence of LRS (12,13). Our findings are consistent with this in both R/R and exposed community members, but also suggest that LRS contribute to the risk of and persistence of probable PTSD, above and beyond 9/11 exposures and individual characteristics. Relative

size of the autoregressive β coefficients indicated that probable PTSD was more stable compared with LRS; however, relative size of the cross-lagged β coefficients showed a similar predictive power of each condition on the other. The effects of 9/11 physical exposures on chronic probable PTSD or LRS were mediated, in part, by the presence of the other condition in both R/R workers and exposed community members. The similarity of findings in these distinct groups lends further support for a PTSD-LRS link; the development of probable PTSD and LRS after physical WTC exposure seems to have been followed by a persistent interrelationship between respiratory and psychological symptoms in both R/R workers and community members, despite the markedly different 9/11 physical exposures experienced by these groups. Furthermore, these mediation effects were similar in magnitude, which further suggests that, although probable PTSD should be considered a risk factor for persistent LRS, LRS may be equally predictive of chronic PTSD. That our findings diverge slightly from previous findings that probable PTSD partially mediated the 9/11 exposure-LRS relationship, but not vice versa (12,13,31), may be in part due to differences in the study populations assessed and follow-up periods. Unlike previous studies that primarily included 9/11-exposed responders who had previous training or experience in disaster response, our sample of R/R workers included some nontraditional responders who were not previously trained in disaster management. It is possible that level of training had an impact on the risk of mental health disorders, such as PTSD, or that mental health symptoms were initially underreported by some traditional responders (2). It is also possible that our study was able to detect a bidirectional relationship between probable PTSD and LRS because of increased statistical power due to the inclusion of three time points rather than one or two, as in the previous studies. Finally, our models included an indicator of psychological 9/11 exposure, allowing us to account for the effect of high psychological distress on the probable PTSD–LRS relationship over time.

Along with dust cloud exposure, high psychological exposure was the strongest predictors of chronic probable PTSD and LRS over the 10-year period, particularly among exposed community members. Our novel finding is that the contribution of probable PTSD to the psychological exposure–LRS relationship seemed to be greater than the contribution of LRS to the psychological exposure–probable PTSD relationship. Although this finding suggests that the observed link between 9/11 psychological exposure and chronic LRS is partially due to the presence of probable PTSD, data on whether this association is due to increased sympathetic activity and immune system dysregulation, inadequate physical symptom reporting due to information processing biases, or other factors are lacking.

WTC-related evacuation from the home or workplace was not associated with either condition. This finding may reflect that evacuated community members included those who had a high level of exposure (requiring that they leave) and those who had less exposure because they left before they were heavily exposed (1,32).

Although the study has several important strengths, such as a large sample size of R/R workers and exposed community members, inclusion of both physical and physiological 9/11 exposures in the model, and the ability to adequately test mediation hypotheses due to longitudinal data with three time points, our findings should be evaluated in light of several limitations. First, LRS and PTSD symptoms were self-reported, and LRS reporting instructions changed slightly in wave 3 (i.e., instructions explicitly asked to report LRS not occurring during a flu or cold). However, although there is a possibility of differential symptom reporting between the follow-ups, thus affecting the strength of the relationships reported in our study, self-reported LRS in community members have been validated in two Registry case-control follow-up studies (7,33), lending support for its reliability. In the both studies, LRS (past 30 days new cough, wheezing, and/or shortness of breath since 9/11) correlated with pulmonary function, especially impulse oscillometry, regardless of the modified instructions in wave 3 survey. WTC exposure was reported retrospectively and was thus subject to recall bias. Lack of data on post-9/11 traumatic events precluded adjusting for these effects in the analysis, possibly resulting in an overestimate of the association between WTC exposures and LRS and probable PTSD. Although LRS, probable PTSD, WTC exposures, and covariates were categorized based on clinical cutoff points or statistical considerations, such practice might have resulted in a loss of important variability, as categorized factors lack granular information above and below the cutoff point. Furthermore, like most postdisaster evaluations, this study likely is subject to selection bias; the enrollment of 70% of the original Registry sample was self-referred to the Registry. However, the Registry's findings on LRS and probable PTSD among self-selected enrollees have been similar to findings among enrollees recruited from lists provided by lower Manhattan employers. Findings have also been comparable with those among exposed members of the New York City Fire Department, where a census of workers is available for analysis (34,35). Finally, our decision to include only respondents with complete data through three surveys resulted in an undercount of the number of registrants with probable PTSD at wave 3 because enrollees with probable PTSD at wave 1 were less likely to participate in subsequent surveys (36). It is possible that this undercount led to an underestimation of LRS and probable PTSD comorbidity as well. Likewise, the greater nonparticipation in all three surveys among respondents who were older, non-Hispanic white, and married, and with greater education could have affected the magnitude of the estimates, despite adjusting for these characteristics in the analyses. However, bias analyses of the WTC data suggest that the effects based on incomplete data are typically underestimated (35). Future investigations of the relationship between PTSD and LRS in the context of 9/11 exposure should use innovative analytic approaches, particularly those that allow for modeling of the individual change in addition to average change (37) and quantifying the degree to which PTSD and LRS mediate each other over a long follow-up. Such studies are needed to reinforce current findings by offering insight into the LRS-PTSD link at the individual level, thus providing a stronger support for causal relationship between both outcomes. Furthermore, in addition to commonly assessed acute 9/11 exposure, future studies should study the relationship between PTSD and LRS in the context of chronic occupational and environmental exposures, as it may explain some of the observed association (38). Finally, establishing that a variable statistically mediates a proposed relationship does not definitively prove that such variable is a primary agent of change. It may merely represent a marker of an alternative mediator or be causal in the presence of a set of additional mediators. Future studies should evaluate models with plausible, theoretically based multiple mediators (37).

CONCLUSIONS

PTSD and LRS are often chronic and are interrelated in complex ways. In our study, probable PTSD and LRS each mediated the other, with subtle differences in patterns seen in R/R workers and community members. The bidirectional relationship between probable PTSD and LRS highlights the need for long-term screening and care for both conditions among exposed rescue/recovery workers and community members, particularly when exposure involves high levels of toxic airborne pollutants and extreme psychological exposures. A diagnosis of either condition should trigger assessment for the other, and treatment should be carefully coordinated. Future studies should quantify the strength of the PTSD-LRS relationship at the individual level and address the impact of coordinated treatment on both conditions and overall well-being, as effective and simultaneous treatment of both conditions holds promise for improvements in physical and mental health (31).

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