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The World Trade Center evacuation study: Factors associated with initiation and length of time for evacuation

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SUMMARY

On 11 September 2001, one of the largest workplace evacuations in the U.S. history took place. The evacuation was largely successful: an estimated 87% of all occupants in World Trade Center (WTC) Towers 1 and 2 exited in less than two hours. Evacuation times, however, were highly variable and not entirely explained by the engineering parameters of the buildings. To understand the complexity of factors that potentially influenced the evacuation time on 11 September, 2001, an interdisciplinary research study was conducted by public health scientists from the Mailman School of Public Health at the Columbia University in the New York City. Analysis of survey data collected from a sample of 1444 evacuees identified several facilitators and barriers to length of time to initiate and fully evacuate from WTC Towers 1 and 2. At the individual level, these included sociodemographic and occupational variables, health status, sensory cues, risk perception, delaying behaviors, and following a group or an emergent leader. At the organizational level, factors included emergency preparedness safety climate variables. Structural (environmental) factors included egress route barriers, poor signage, congestion, and communication system failures. Many factors identified in the study are modifiable. Therefore, these data have the potential to inform high-rise preparedness and response policies and procedures.

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KEY WORDS: high-rise evacuation; evacuation time; emergency preparedness; pre-evacuation delay; organizational safety climate

INTRODUCTION

The magnitude and severity of 11 September 2001 attack resulted in the need to effect a rapid and full evacuation of the World Trade Center (WTC) complex, including the two super skyscrapers, WTC Towers 1 and 2. The process is considered to have been successful, with a large majority of occupants below the point of impact able to evacuate [1]. Both structural and organizational changes that were made in the aftermath of the 1993 WTC bombing facilitated a more timely egress in 2001.

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However, not all those believed to have been capable of exiting on September 11th did so. Many human factor experts have argued that safety will be improved by understanding how humans actually behave in emergency situations and by accommodating these behaviors through building design and evacuation planning [2, 3]. Although some patterns of human behavior in emergencies, such as fires, have been identified, these behaviors are complex and only partially predictable [4–10]. Human behaviors in high-rise occupancies are particularly not well understood. Because of robust designs and extensive fire safety features, high-rise occupancies are rarely fully evacuated; prior to 2001, full-scale evacuation drills were seldom performed. Consequently, data on emergency response behaviors of high-rise occupants are quite sparse [11]. Even in the New York City (NYC), which has one of the greatest concentrations of high-rise occupancies in the world, with roughly 2000 high-rise business occupancies and 2400 high-rise residential occupancies, and a well-regarded fire safety program, the dynamics of high-rise evacuations are not well characterized or understood. This fact was underscored by the 1993 WTC bombing; when firemen conducted a final sweep through the towers, they found workers still at their desks six hours after the evacuation order was first issued [12].

To more fully explicate the role of individual and organizational factors within the existing structural parameters and unfolding environmental conditions on 11 September 2001, three different research teams examined the evacuation process. The NYC-based team, led by public health scientists from Columbia University's Mailman School of Public Health, addressed their research question from an epidemiological perspective. That is, given an average length of time to initiate and fully evacuate the building, after controlling for confounding variables such as starting floor and elevator use, the team sought to identify both risk factors and facilitating factors that potentially led to increases or decreases from the referent mean time points. The overarching goal of the NYC-based team was to identify potentially modifiable characteristics that could inform both policy and practice, thus leading to improvements in high-rise safety. Given this public health perspective, the study was especially focused on the identification of population-based risk reduction recommendations rather than individual-based interventions.

The NYC-based study, referred to as the World Trade Center Evacuation Study (WTCES), was designed to identify factors significantly associated with three major evacuation-related study outcomes. These outcomes were: length of time to initiate evacuation, length of time to fully evacuate either WTC Tower 1 or Tower 2, and risk of injury. This paper reports on the two time-related outcomes.

METHODS

The five-phase WTCES study that was conducted over a period of slightly less than four years, utilized a quasi-experimental, mixed-methods approach, incorporating both qualitative and quantitative methodologies, all guided by a participatory action research (PAR) framework (see, Figure 1, for an overview of the study design) [13, 14]. This meant that from the earliest inception of the project, and in keeping with published guidelines on the ethical conduct of disaster research, study participants (i.e. WTC evacuees) and other key stakeholders were involved in formulating the study questionnaire, data collection procedures, and feedback and dissemination plan [15, 16].

At the conclusion of the data analysis phase, two PAR teams were formed. These were composed of WTC disaster evacuees and study investigators, with outside expert advice from consultants with a wide range of expertize, including fire safety, engineering, disaster mental health, emergency planning, occupational safety, and high-rise building management. Over an extended period lasting several months, the team members worked to identify data-driven strategies that might address the most significant risk factors that potentially impacted the three major study outcomes (i.e. initiation of evacuation, length of time to evacuate, and risk of injury). The PAR teams' practical, targeted, and readily implementable recommendations have been published [17].

All study procedures involving human participants had prior review and approval of the Columbia University Medical Center Institutional Review Board, and informed consent was obtained from each participant enrolled in every phase of human research. An additional level of protection of

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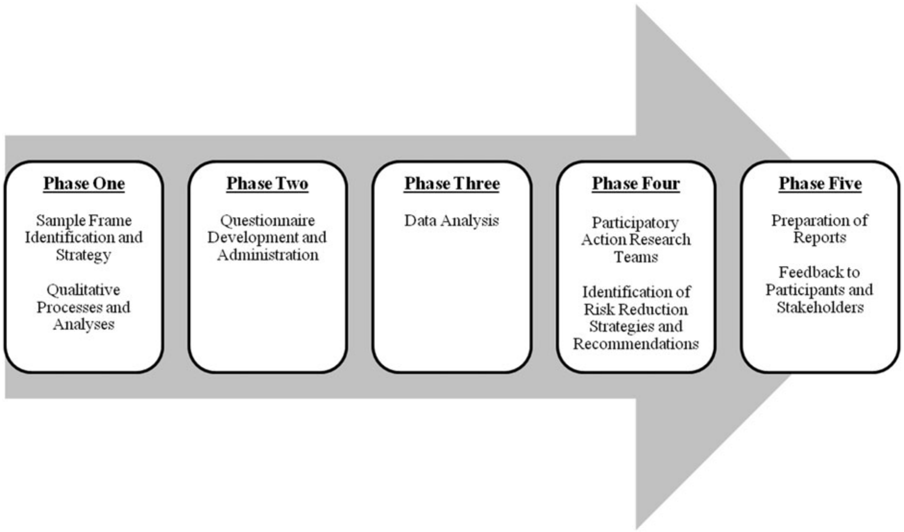

Figure 1. Multiphase study design.

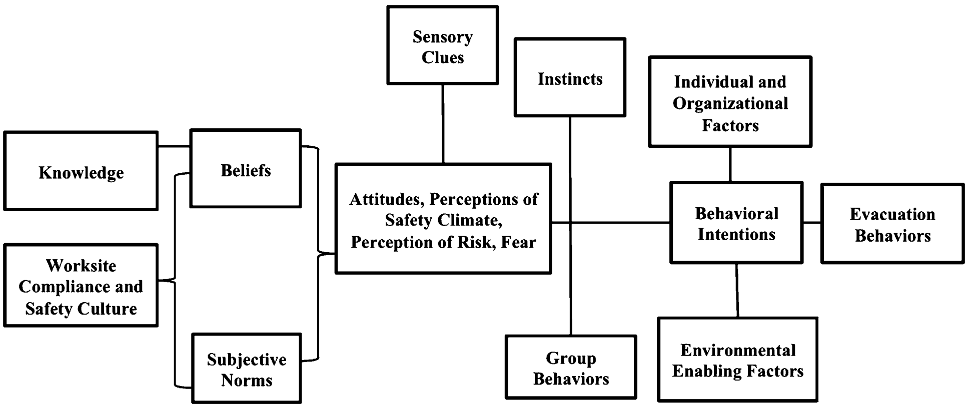

Figure 2. WTCES model.

the confidentiality of the data obtained in the study was provided by obtaining a Certificate of Confidentiality from the U.S. National Institutes of Health. Details on the extensive steps to protect human subjects that were taken have also been published [18].

Study design

In close collaboration with a multidisciplinary Advisory Board, a conceptual framework was developed (see, Figure 2) [19]. This framework was derived from DeJoy's Behavioral Diagnostic Model, which itself is an adaptation of Green's PRECEDE model [20, 21]. The new model emphasized the inter-connectedness between the individual and work environment, as well as the importance of risk beliefs and attitudes in precaution adoption in the workplace. The framework led to the development of key study constructs. These were then operationalized into specific survey items, which are described in further detail below.

The resultant ten-page, 95-item questionnaire included both worker-centered constructs as well as organizational safety attributes, sometimes referred to as organizational 'safety culture/climate' [22]. Organizational and structural determinants (enabling factors) that influenced employees' adoption of safety behaviors (e.g. fire drills, emergency lighting that allows employees to exit when the power fails, width of egress doors, number of stairwells, etc.) were also operationalized for inclusion on the questionnaire.

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Copies of the survey were prepared in both paper- and Internet-based formats. Extensive validation procedures were then performed, including content, criterion, and construct validity procedures. The final draft questionnaire also underwent extensive cognitive testing and pilot testing, including pilot tests of the Internet version of the questionnaire. Response categories predominantly included multiple choice items and Likert-type scales, although three questions were open ended. Copies of the questionnaire, codebook, and information on the psychometric properties of the instrument are available by contacting the corresponding author.

Study measures

Questionnaire items addressed the following five major constructs:

(*1*) *Individual Risk Factors*

Individual risk factors included sociodemographics and job characteristics, health and injury status, familiarity of the building and knowledge of the fire safety program, prior emergency experience, peri-event cues, evacuation and safety-related beliefs and attitudes, peri-event behaviors, attitudes, and perception of risk and evacuation route.

Sociodemographics and job characteristics. Items were included on age, gender, race/ethnicity, education, marital status, children, and place of residence on 9/11. Items on occupation, employment, tenure, location (building and floor) on 9/11, union membership, management responsibilities, membership on company's fire safety team, and safety and emergency response prior experience (e.g. military, firefighting, Emergency Medical Services [EMS] experience) assessed participants' job characteristics.

Health status/injury status. Three items with embedded questions assessed health status, namely: experiencing a disability or other medical conditions, smoking habits, and other health issues that could have affected one's ability to walk down a large number of stairs (e.g. broken leg, pregnancy, 'flu', obesity, physical fitness, or any other illness or condition). A set of questions related to injuries sustained in the towers was included: number, type, and severity of injuries were addressed.

Familiarity and knowledge with the building and its fire safety features. A number of items addressed participants' familiarity and knowledge of the building, including: the location of sky lobby floors, roof access for escape, and procedures to follow if an emergency alarm sounded. An additional set of items assessed fire drill participation in the WTC. In addition, based on psychometric analysis performed at the conclusion of pilot testing, other items comprised a new ten-item scale, referred to as the *Emergency Preparedness Knowledge and Experience Scale.* This scale measures familiarity and knowledge of the building, as well as prior emergency experience. The following items were included: number of stairwells, location of exit doors, non-reentry floors, location of exit doors on sky lobby floors, where all stairwells would lead, the number of fire alarm pull boxes on the floor, being able to safely leave without directions, degree of familiarity with the building, participation in fire drills, and history of the previous evacuation from the building. An internal consistency estimate of responses to the ten-item scale yielded a Cronbach alpha of 0.77.

Peri-event sensory input. Peri-event sensory cues (i.e. building/environment conditions) were assessed using a checklist of items that included auditory, olfactory, visual, and physical signs, for example, the presence of smoke, water, flames, etc.

Beliefs, attitudes, and perception of risk. Several items addressed risk perception, including perceived seriousness of the situation, and concern that the building would collapse. Other items were included on evacuation-related safety beliefs and attitudes, e.g. responsibility for one's safety, whether or not the evacuee believed authorization or permission was needed prior to evacuation, importance of fire safety in the workplace, and belief in one's preparedness based on prior safety training.

Peri-event behaviors and activities. A number of items were included on activities that could conceivably impact the initiation of evacuation. These included various behaviors, such as gathering personal items, seeking out others, making or attempting to make phone calls, finishing work-related tasks, changing shoes, etc. Other items addressed how participants behaved (e.g. acting in a

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calm manner), instinctual behavior, information-seeking behavior, means of obtaining information, and the evacuation process itself.

The questionnaire included items on the guidance (if any) that was provided by an emergent leader and the qualities these leaders demonstrated. The influence of co-workers (i.e. subjective norm) on the evacuation process was also assessed.

Finally, several items addressed the evacuation route and means of evacuation (i.e. stairs, elevator, or escalator), number of people in elevator upon evacuation (if this method of egress was used), reasons for taking that route, and any changes in egress route. Several items addressed stopping, the numbers of stops, and the reasons for stopping (e.g. to rest, help others, because of crowding, due to injuries sustained or other health reason, to make phone calls, to find less-congested stairwells, etc.), immediate actions taken after reaching the street, conditions on the street, one's ultimate destination after evacuation, and means of transit after building evacuation.

(*2*) *Organizational risk factors*

Organizational risk factors included key elements of emergency preparedness as required under the U.S. Occupational Safety and Health Administration (OSHA) [23]. For example, items addressed the designation of an individual responsible for ensuring that everyone evacuated (e.g. floor warden or searcher), the provision of written fire safety and evacuation information, post-evacuation-designated meeting places, and plans for conducting a head-count, designated person incharge of fire drills, and management and co-worker participation in fire drills. These items formed a new eight-item construct referred to as the *Emergency Preparedness Safety Climate Scale*. An internal consistency estimate of the responses yielded a Cronbach alpha of 0.66.

Four organizational risk factor items addressed disability preparedness. This new scale, referred to as the *Disabilities Preparedness Scale*, was designed to assess the organizational preparedness for evacuation of persons with disabilities (PWD). These items included whether a specific area was designated for PWD to gather during an emergency, specific plans for evacuating PWDs, whether or not co-workers were assigned to assist PWDs during an emergency, and availability of evacuation equipment for PWDs. An internal consistency estimate of the responses to the four-item scale yielded a Cronbach alpha of 0.76.

(*3*) *Structural risk factors*

Many items, with several embedded questions, addressed structural (environmental) risk factors. These were: environmental conditions immediately following the impact and during the evacuation (e.g. poor lighting, overcrowding, smoke or dust, fire/intense heat, water, structural damage or debris, doors that would not open, poor, missing, or confusing signage, and operability status of the public address system (PA)).

(*4*) *Length of time to initiate evacuation*

In order to estimate the time to initiate evacuation, participants were asked to recall certain key points of time, e.g. at what time they: first became aware 'something unusual had happened', concluded that 'something serious had happened', 'made the decision to evacuate', and 'began to evacuate.' A timeline of the events of that morning was included in the questionnaire to provide a point of reference (please see Figure 3).

(*5*) *Length of time to complete evacuation*

In order to estimate the length of time to complete the evacuation process, participants were asked to recall the time points (using the prompt provided) when they completed key steps to fully evacuate the building, including the point in time when they 'began to evacuate', 'reached street

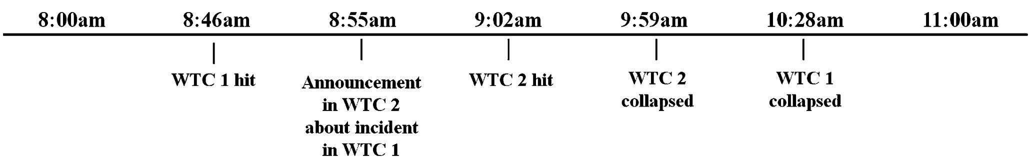

Figure 3. Timeline of events on the morning of 11 September 2001.

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level', and 'exited to the street.' Data on their initial and final destination, route taken, and length of time to reach these destinations were also collected (Zimmerman, in press).

Participant recruitment and survey administration

A convenience sample of WTC evacuees was constructed from two major sources: (1) a large, random sample of WTC employees selected from a security badge list compiled by the Port Authority of New York and New Jersey (PANYNJ) and (2) the NYC Department of Health and Mental Hygiene WTC Health Registry. Further details on the recruitment of study participants are available elsewhere [19]. Of the 1767 people who worked in WTC 1 or 2 at the time of the attacks who completed the study questionnaire, 1444 reported actually evacuating the buildings on 11 September 2001. These individuals comprised the final data set. This cohort was compared to the 323 people who had worked in the towers but who did not actually evacuate (i.e. they were still in transit to work that day or were absent), and no significant demographic differences were found between the two groups (data not shown).

A total of 943 individuals completed the paper version of the questionnaire, and the remainder completed the web-based version. A comparison of the demographic characteristics of respondents by questionnaire format revealed no statistically significant differences, except for the finding that Port Authority individuals (31%) were more likely ($p<0.05$) to complete the web-based version than did WTC 1 (16%) or WTC 2 (15%) evacuees. No participant differences by age, gender, or other demographic variables were noted between the two survey formats.

Data analysis

Pilot test data were examined to determine the quality of data obtained for each item. This included checking for floor and ceiling effects, bimodality, consistency of responses (cross-validation), etc. Exploratory factor analyses were then conducted. Factors were retained based on their eigenvalues of one or greater and the factor loadings obtained using orthogonal varimax rotation. This served to refine the three new scales and to shorten the final questionnaire.

Once the full data set was finalized, and after data-editing procedures and checks for internal reliability and validity of responses, an array of descriptive statistics was performed (e.g. frequencies, histograms, and measures of central tendency and dispersion). Graphical techniques were used to characterize the distribution of variables, starting at the most refined level of measurement. This strategy provided familiarity with the data and allowed us to determine if the data met assumptions required by the intended statistical testing procedures. Point estimates were utilized to estimate population values on all variables. Once individual variables were validated, all scales underwent psychometric analysis (e.g. inter-item correlations, including the determination of Cronbach's alpha). Subsequent analyses were based on these final scales.

Descriptive statistics for subsamples of interest, such as building and worker-related variables, such as gender, education, age, and health status (physical challenges, etc.), and prior emergency experience were also generated. To determine the independent and joint relationship of various factors with evacuation outcomes (e.g. length of time to initiate and fully evacuate) chi-squared and odds ratio (*OR*) statistics were performed. Variables that were statistically significant in the bivariate models were incorporated into multivariate models where feasible. Starting floor, elevator use, and other potentially confounding variables were controlled for in multiple logistic regression models.

RESULTS

Individual factors

Demographics. A majority (58%) of the participants were male, with an average age of 44 years (ranging from 22 to 80 years). Most were well educated; 90% reported 13 or more years of education. On 9/11/01, most participants (56%) lived outside the NYC, 32% lived in neighboring

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boroughs, 11% lived in Manhattan, and 2% lived south of the Canal Street in Lower Manhattan. The average tenure at their WTC place of employment was six years. Thirty-six percent reported that they held supervisory or management positions. A fairly substantial proportion (17%) of respondents reported that they were members of their company's fire safety teams. In addition, 11% of the sample had experience with the military, 6% safety/security experience, 3% had fire-firefighting or EMS experience, and 2% law enforcement. A sizable proportion (17%) of participants were members of their company's fire safety team, generally serving as a searcher or floor warden. See Table I for a summary of demographic information.

Health status/injury status. Given the relatively young average age of the cohort, surprisingly a large proportion of respondents (23%) reported medical conditions or disabilities, which included: respiratory problems (28%), mobility problems (21%), mental health problems (15%), heart conditions (12%), and sensory deficit (8%). Of these, nearly one-third indicated that this condition affected their ability to walk down a large number of stairs. In addition to these conditions, another 7.2% of the cohort reported that on 11 September 2001, they had an existing health issue (e.g. 'flu', pregnancy, broken leg, obesity, etc.) that affected their mobility.

In terms of injuries, 37% of the sample reported sustaining an injury on 9/11. The most prevalent injuries were psychological, respiratory, bruises, cuts, and broken bones.

Familiarity and knowledge with the building and its fire safety features. Participants were generally unaware of the design and fire safety features of their building. For instance, only 22% knew the location of the sky lobby floors, and only 20% knew the appropriate action to take when the alarm sounded. Participants were unsure about using the roof as an egress point; 26% thought that the roof could be used as a means of escape in case of fire or other emergency, and another 25% were not sure whether this was a possible means of escape.

The results on the *Emergency Preparedness Knowledge and Experience Scale* indicated low levels of emergency-related knowledge among evacuees. The mean scale score was 3.26 with a standard deviation (SD) of 2.37; median = 3.0, mode = 3.0, and range = 0–10. Responses on individual items within the scale further reflect this low level of knowledge. For example, less than half (42%) knew that there were three sets of fire stairs in the building, and only 20% were confident that they knew the location of all exit doors that led to stairs on their floor. Forty-five percent did not know that certain floors were locked for security reasons. Seventy-two percent did not know the location of stairwell exit doors on the sky lobby floors, 86% did not know where all the stairwells would lead, and 95% did not know the number of fire alarm pull boxes on their floor. We also examined the scale scores for select subgroups, and respondents with either fire safety team membership or Port Authority employment had higher scale scores (greater than the mean scale score) compared to other respondents; $OR = 4.00$ (95% Confidence Interval [CI] = 2.78–5.75), $p < 0.001$, and $OR = 11.10$ (95% CI = 6.18–19.23), $p < 0.001$, respectively.

Many respondents (50%) reported that they did not feel confident about exiting their building without directions from fire or security staff. Few individuals reported familiarity with their building; only 21% felt that they were very familiar, and 56% reported that they were somewhat familiar with their building.

Most participants had fire drill experience. Eighty percent of the sample reported a history of participation in a fire safety drill in their building; 98% reported at least one fire drill in the previous 12 months (Mean $[M] = 2.54$, Standard Deviation $[SD] = 2.45$). However, *only 10%* reported that they had ever actually entered a stairwell as part of the drill, and only 6% had ever exited the building as part of a drill. Before September 11th, 27% of the sample reported fully evacuating their building for any reason. Twenty-two percent of the entire sample of 1444 evacuees) reported leaving during the 1993 WTC bombing.

Peri-event sensory input. In the initial few moments after WTC 1 was impacted, many participants reported that the first cue that something unusual had occurred was the sound of a tremendous crash. Most also reported simultaneously feeling the building sway. Soon after the swaying, the next most prevalent cue was the smell of burning fuel, followed by smoke, and, especially at the south-face, a view of paper and debris falling by their office windows. For some evacuees located in very low floors, including the basement level floors, the first cue experienced was a terribly loud

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Table I. Demographics of the sample, $N=1444$*.

Characteristic	N	Valid %[†]
Building evacuated		
WTC 1	733	51.0
WTC 2	704	49.0
Gender		
Male	823	57.5
Female	608	42.5
Age (years)	$\bar{x}=43.66$	SD$\pm$10.72
Race/ethnicity		
Caucasian	1139	79.4
African American	95	6.6
Hispanic	83	5.8
Asian/Pacific Islander	71	5.0
Other	20	1.4
More than one	26	1.8
Education		
Less than high school	5	0.3
High school	133	9.3
Some college	282	19.7
College or more	949	66.2
Other	65	4.5
Tenure (years)		
WTC 1	$\bar{x}=6.14$	SD$\pm$7.32
WTC 2	$\bar{x}=5.85$	SD$\pm$5.52
Place of residence on 9/11		
Lower Manhattan	24	1.7
Other part of Manhattan	156	11
Neighboring Borough	453	31.9
Outside NYC	789	55.5
Employment sector on 9/11		
Private industry	1194	84.1
Government	226	15.9
Manager or supervisor		
Yes	513	35.8
No	919	64.2
Union membership		
Yes	104	7.2
No	1334	92.8
Service experience		
Military	165	11.4
Firefighting or EMS	37	2.6
Law enforcement	26	1.8
Safety/security	82	5.7
Member of fire safety team		
Yes	239	16.7
No	1190	83.3
Spouse or domestic partner		
Yes	1002	70.1
No	428	29.9
Children or other live-in dependents		
Yes	690	48.1
No	746	51.9
Dependents ages 8–15		
Yes	311	42.5
No	420	57.5
Smoker		
Yes	267	18.6
No	1166	81.4
Years smoked	$\bar{x}=17.94$	SD$\pm$10.96
Packs smoked per day	$\bar{x}=0.86$	SD$\pm$0.6
Disability or diagnosed medical condition		

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Table I. *Continued.*

Characteristic	*N*	Valid %†
Yes	322	22.5
No	1112	77.5
Any other health condition on 11 September		
Yes	100	7.2
No	1298	92.8

*Values may not add to 1444 due to missing values.
†Percentages reflect valid responses.

noise accompanying the crashing of the oversized elevators, which resulted when their cables were cut by the force of the impacting aircraft. Some individuals located in north-facing WTC 1 offices actually saw the plane heading toward their building. Similarly, several participants located in WTC 2, with north-facing windows, reported seeing the plane approaching WTC 1 and the resultant damage to that building. In terms of frequency, hearing something unusual was most prevalent (69%), followed by feeling something unusual (the sway) (65%), seeing something unusual (61%), and smelling something unusual (18%).

Beliefs, attitudes, and perception of risk. A large proportion of the sample (70%) reported that they decided to evacuate because they believed they were in danger, although, in terms of the seriousness of the situation, 49% initially thought the event was serious and they would have to evacuate immediately. A smaller proportion (15%) thought that the situation was minor and therefore they did not initially even consider evacuating.

Similarly, very few (18%) participants thought that their building was in danger of collapsing. Many people evacuated not because of their own perception of risk, but for other reasons, including: 'someone told me to leave' (50%), 'past personal experiences' (20%), 'concern for their family' (16%), and 'input from telephone or personal digital assistants (PDA)' (4%).

Respondents reported feeling reluctant to evacuate for a variety of reasons, including: 'doing so might adversely affect my employment' (2%), 'my immediate supervisor would not approve' (2%), 'I might lose pay' (0.5%), 'I did not want to waste time in the event of a false alarm' (5%), and 'other' (16%).

There was a general perception that responsibility was shared between the individual, the managing director of the PANYNJ and their employer. For example, while a large proportion (71%) of respondents felt personally responsible for their own safety in the WTC buildings, a similar proportion (70%) reported that the PANYNJ also had that responsibility, and additionally, 54% also thought that their employer had that responsibility. A large majority of the sample (84%) reported that they believed nothing was more important that one's personal safety in the workplace.

In terms of their fire safety training experience, a large proportion of the sample (60%) did not believe that the fire safety training they had received prepared them to evacuate the building.

Peri-event behaviors and activities. When initiating their evacuation, once respondents had decided to leave but before they actually began, a large proportion (74%) reported performing various activities. These included: gathering items (40%), seeking out friends/co-workers (33%), searching for others (26%), making phone calls (18%), shutting-down computer or other computer-related activity (8%), waiting for directions (7%), gathering safety equipment (5%), changing shoes (3%), and trying to obtain permission to leave (1%). Many respondents (32%) reported that they left in a crowd under the direction of an emergent leader. Characteristics of these leaders included being calm and directive, having an authoritative voice, and being knowledgeable. A large proportion of participants (33%) also reported that they were influenced by a group of co-workers.

Information seeking was common, with most information obtained from face-to-face communication (42%), followed by PA announcements (12%, WTC 2 evacuees), followed by landline telephones (8%), televisions (7%), cell phones (7%), radios (4%), and pager/wireless/PDAs (4%). Forty percent of the participants decided to leave based on the information obtained from these sources.

A very high proportion of the sample (96%) reported that they acted calmly during the evacuation. The most frequently given reasons for acting this way were the following: 'others remained calm', 'I provided emotional support to others', 'I did not feel my life was in danger', 'thoughts of my family/friends', 'my faith and spirituality', and 'I was concerned others would panic if I panicked.' The most influential factors in motivating the evacuation, in the words of the study participants on an open-ended question, were the following: 'gut instinct', fear, family, and faith.

With respect to the means of evacuating the building, 88% initially used the stairs, 8% used the elevators, and 2% used the escalators, the remainder used some combination. People who rode the elevator estimated that there were, on an average, 20 people in the elevator with them (range = 1–50). A sizable proportion (26%) of participants reported difficulty in following stairwell routes. Once evacuation was underway, switching stairwells was not uncommon; 20% of the sample reported switching at least once and 60% stayed with only one stairwell until they exited. The most common reasons to switch routes were because respondents were instructed to do so or because the first route was impassable (e.g. too crowded, blocked by debris, or too much smoke). Eight percent of the sample reported that inappropriate shoes slowed them down as they descended (i.e. caused them to stop and/or remove shoes). On an average, evacuees stopped four times during their evacuation, and the most common reasons for stopping included: overcrowding (46%), helping others (20%), because they were directed to do so (15%), because they were tired (7%), and because their path was blocked by debris (7%).

At the street level, 38% of participants reported difficulty in finding exits leading to the street, with 34% ultimately exiting through an exit they were unfamiliar with. Eight percent of respondents were unfamiliar with the street they exited onto. Once they reached the street, half of the participants reported that they did not immediately leave the area. The reasons given for not immediately leaving were: stopping to see what was happening and to get more information or assistance (36%), looking for friends or co-workers (26%), stopping to use the phone (15%), not knowing where to go (14%), heavy traffic, crowding (10%), not given any directions (8%), and needing to rest (8%). In the immediate vicinity, the following conditions were observed: debris (62%), dust, smoke, and poor visibility (38%), public transportation not running (36%), police blockades (26%), and shoes missing (12%). Prior to the subways closing that morning, 4.8% were able to use subways to reach their first destination. Others used buses (2%), ferries (2%), cars (1.7%), emergency vehicles (1.7%), and taxis (1%). By far, most participants (91%) walked to their first destination.

Organizational factors

The mean scale score on the *Emergency Preparedness Safety Climate Scale* was quite low (mean = 2.83), with an SD of 1.88, median = 3.0, mode = 3.0, and range = 0–8. Scores on the individual items for this scale mirrored this. For example, 33% did not know or were not sure if someone on their floor was incharge of ensuring that everyone on their floor evacuated. Only 26% reported that they were provided with written fire safety information, and only 18% were aware of a written evacuation plan provided by their employer. Eighty-four percent reported that they had never been apprised of plans for gathering after an evacuation, and only 15% reported that their employer had a plan to conduct a head count. Fire safety team members and Port Authority employees scored higher (above the mean) on the *Emergency Preparedness Safety Climate Scale* than evacuees not in these positions; $OR = 2.54$ (95% CI = 1.82–3.53), $p < 0.001$ and $OR = 2.23$ (95% CI = 1.53–3.25), $p < 0.001$, respectively. Furthermore, the participants who had more emergency preparedness knowledge and familiarity with the WTC towers (i.e. scored above the mean score on the *Emergency Preparedness Knowledge and Experience Scale*) were over four times more likely to score higher on the *Emergency Preparedness Safety Climate Scale* ($OR = 4.32$, 95%CI $= 3.36 - 5.56$, $p < 0.001$).

A large number of respondents (52%) reported that fire safety drills were primarily conducted by the fire safety director of the PANYNJ, and nearly one-third (27%) reported that their employer conducted the fire safety drills. Sixty percent reported that their supervisor participated in these drills, and 69% reported that their co-workers were active participants in these drills.

On the *Disability Preparedness Scale*, an extremely low mean score of 0.32, with an SD of 0.83, was obtained; median = 0, mode = 0, and range = 0–4. Although a fairly substantial percentage of

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participants (28%) reported that a person with a disability was located on their office floor, only 5% knew of a specially designated gathering area for persons with disabilities. Eleven percent stated that there was a plan in place for evacuation of persons with disabilities, 10% thought that someone was assigned to assist them, and 8% knew of special equipment available to assist them. Once again the scale scores were examined for select subgroups. Fire safety team members were four times more likely to score above the mean score on the *Disability Preparedness Scale* ($OR = 4.00$, 95% CI = 2.78–5.75, $p < 0.001$) and Port Authority employees were almost thirteen times more likely to score above the mean score ($OR = 11.10$, 95%CI = $6.18 - 19.23$, $p < 0.001$).

Structural factors

On September 11th, structural and environmental problems increased with time as the building structure continued to degrade. For example, in the hallways, 9% reported that they encountered doors that would not open, 5% saw flames, and poor, missing, or confusing signage was reported by 4%. In the stairwells, respondents encountered water (30%), smoke or dust (26%), structural damage and debris (14%), and poor lighting (9%). More than half (58%) reported overcrowding.

Many respondents reported pre-9/11 structural problems related to the PA, which was upgraded after the 1993 bombing. For instance, only 59% reported that they could routinely hear the PA announcements clearly. False fire alarms were also problematic in that 26% of respondents reported false alarms sounding monthly or more frequently. Of concern was that prior to 9/11, 24% of respondents stated that they never heard *any* announcements.

A large proportion of respondents from WTC Tower 2 (64%) were aware of the announcement made over the PA system regarding the incident in WTC 1. Most (86%) became aware by actually hearing the announcement, and 9% were informed of the announcement by someone else.

Major outcomes

Length of Time to Initiate Evacuation. On an average, evacuees in both towers had a 6-min delay between the moments the buildings were impacted to the point of initiating their evacuation. The range of initiation times varied from virtually within seconds of the first impact to as lengthy as 44 min for both towers. See Table II for detailed initiation times.

Length of Time to Fully Evacuate. The length of time to fully evacuate varied significantly by tower. As shown in Table II, WTC 1 evacuees took, on average, 40 min to fully evacuate whereas evacuees from WTC 2 took 22 min. The range varied substantially by tower as well. In WTC 1, length of time to fully evacuate ranged from less than 1–102 min. In WTC 2, the range was less than 1–72 min (see, Table II for full evacuation times).

The rate per floor was estimated after controlling for the use of elevators and stratifying by zone to control for number of floors; on an average WTC 1 evacuees descended at a rate of 60 s per floor, while WTC 2 evacuees descended at a rate of 30 s per floor. This exceeded the 57 min

Table II. Key time periods* for evacuees in WTC† 1 and 2 on 11 September 2001.

	WTC 1		WTC 2	
Time period	Mean	Range	Mean	Range
First became aware	8:46	08:46–09:20	8:47	08:46–09:02
Made decision to leave	8:51	08:46–09:30	8:52	08:46–09:30
Began to leave	8:52	08:46–09:30	8:53	08:46–09:30
Reached street level	9:32	08:46–10:28	9:15	08:46–09:58
Length of time to initiation	6 min	<1–44 min	6 min	<1–44 min
Length of time to fully descend‡	40 min	1–102 min	22 min	1–72 min
Rate of time per floor‡	60 s		30 s	

*Hours: Minutes.
†WTC = World Trade Center
‡Controlling for elevator use and starting floor.

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between the time WTC 2 was hit and the time it collapsed because many individuals in WTC 2 started their evacuation process *as soon as WTC 1 was hit* (i.e. they actually saw the plane impact WTC 1).

In WTC 1, 17 people exited the building within 10 min of collapse, and in WTC 2, 23 people exited the building within 10 min of collapse. Nine people exited within 3 min of collapse.

Factors associated with length of time to initiate evacuation

A number of factors were significantly associated with initiation time, as described below.

Individual factors

Sociodemographics and job characteristics. Older participants (age above the mean age of 44 years) were almost one and a half times more likely to delay their initiation ($OR = 1.40$, 95% CI = 1.11–1.78, $p < 0.005$). Participants with experience in the military, firefighting, EMS, law enforcement or safety and security were also more likely to delay their initiation ($OR = 1.76$, 95% CI = 1.30–2.38, $p < 0.001$). Members of fire safety teams were also more likely to delay initiating ($OR = 1.67$, 95% CI = 1.22–2.28, $p < 0.001$).

Health status/injury status. Individuals reporting a disability or medical condition on 9/11 were 1.42 times more likely to delay their initiation, ($OR = 1.42$, 95% CI = 1.08–1.86, $p < 0.02$).

Familiarity and knowledge with the building and its fire safety features. Scores on the *Emergency Preparedness Knowledge and Experience Scale* were not associated with initiation time. However, fire safety team members and PA employees were more likely to score higher on this scale (as noted above).

Peri-event sensory input. Visual cues reported immediately following the impact were associated with delays in initiation time. These included: exits blocked by debris ($OR = 2.16$, 95% CI = 1.17–3.99, $p < 0.02$); fire ($OR = 2.01$, 95% CI = 1.17–3.77, $p < 0.02$); and damage to the walls or ceilings ($OR = 1.48$, 95% CI = 1.07–2.04, $p < 0.02$).

Beliefs, attitudes, and perception of risk. Those who initially assessed the situation as serious were almost four times more likely to initiate more quickly ($OR = 3.78$, 95% CI = 2.93–4.88, $p < 0.001$).

Peri-event behaviors and activities. Participants reporting hesitating for one or more reasons were over three and a half times more likely to delay initiation of evacuation ($OR = 3.71$, 95% CI = 2.72–5.06, $p < 0.001$). Participants who engaged in two or more delaying behaviors (i.e. making phone calls, performing work-related duties, gathering personal items, collecting safety equipment, seeking permission, etc.) were over three times more likely to be delayed in their initiation ($OR = 3.10$, 95% CI = 2.43–3.97, $p < 0.001$).

With regards to the route of evacuation taken, participants taking the closest stairwell were more likely to report a faster initiation than those who did not report taking the closest stairwell ($OR = 1.46$, 95% CI = 1.14–1.88, $p < 0.002$). Those who followed a group were more likely to delay the start of their evacuation than those who did not follow a group ($OR = 1.46$, 95% CI = 1.13–1.88, $p < 0.004$). Similarly, participants who reported that they left in a crowd under the direction of an emergent leader were 1.46 times more likely to delay initiation ($OR = 1.47$, 95% CI = 1.14–1.90, $p < 0.003$).

Organizational factors

Respondents with high safety climate scores were more likely to report shorter initiation times compared to those with low safety climate scores. When controlling for prior military, police, fire or security experience, Port Authority employment, and fire safety team membership, WTC 1 respondents with higher scores on the *Emergency Preparedness Safety Climate Scale* were more likely to initiate more quickly than those with extremely low scores ($OR = 3.25$, 95% CI = 1.08–9.75, $p < 0.04$). Similarly, WTC 2 respondents (no control variables) with higher scores on the *Emergency Preparedness Safety Climate Scale* were more likely to initiate more quickly than those with extremely low scores ($OR = 2.36$, 95% CI = 1.06–5.28, $p < 0.04$).

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Scores on the *Disability Preparedness Scale* were not associated with length of time to fully evacuate.

Structural factors

Participants in WTC 2 who heard any PA announcement regarding the event were likely to delay their initiation ($OR = 1.51$, 95% CI = 1.07–2.14, $p < 0.02$), as the message indicated that an incident had occurred in the other tower, thus making it safe to return to work in WTC 2. Structural damage (to walls and ceilings) and debris were also related to longer initiation times, as noted in the section on peri-event cues.

Factors associated with length of time to fully evacuate

After controlling for starting floor and use of elevators, factors associated with extended length of time (i.e. greater than the mean; mean WTC 1 = 40 min, mean WTC 2 = 22 min), are described below. No relationship was found between initiation time and full length of time to evacuate.

Individual factors

Sociodemographics and job characteristics. Similar to initiation delay, members of fire safety teams were 1.7 times more likely to report lengthier evacuations ($OR = 1.67$, 95% CI = 1.05–2.67, $p < 0.04$).

Health status/injury status. We also controlled for building and fire safety team membership to investigate disability and evacuation time. Participants who reported any disability or medical condition were more likely to report lengthier evacuation times ($OR = 1.67$, 95% CI = 1.03–2.71, $p < 0.04$). Those specifically reporting orthopedic disabilities were more than three times more likely to report a lengthier evacuation ($OR = 3.37$, 95% CI = 1.49–8.12, $p < 0.007$).

In terms of injury, participants who had sustained injuries were more likely to report lengthier full evacuation times. Those with one or more physical injuries took almost two times longer ($OR = 1.88$, 95% CI = 1.29–2.73, $p < 0.001$).

Familiarity and knowledge with the building and its fire safety features. Scores on the *Emergency Preparedness Knowledge and Experience Scale* were not associated with length of time to fully evacuate. Evacuees with prior emergency response experience or a history of membership on a fire safety team had significantly higher scores on the scale compared to those without such experience. After controlling for this experience, we were still unable to detect significant associations with length of time.

Peri-event sensory input. Sensory input was related to delays in the full evacuation. Participants who reported four or more peri-event sensory cues were 1.6 times more likely to have a lengthier evacuation ($OR = 1.62$, 95% CI = 1.05–2.51, $p < 0.03$). In particular, physically feeling something unusual ($OR = 3.80$, 95% CI = 2.49–5.78, $p < 0.001$) was associated with longer time to full evacuation.

Beliefs, attitudes, and perception of risk. Participants who believed that the situation was serious were 1.8 times more likely to have shorter evacuation times ($OR = 1.80$, 95% CI = 1.26–2.56, $p < 0.001$).

Peri-event behaviors and activities. Individuals who reported switching their route (as opposed to not switching) during the full evacuation process were more likely to have lengthier evacuation times ($OR = 3.34$, 95% CI = 2.08–5.38, $p < 0.001$). Participants switching routes because the first route was impassable were also more likely to report lengthier evacuations ($OR = 3.00$, 95% CI = 1.75–5.15, $p < 0.001$). As expected, frequent stopping during evacuation (one or more) was also associated with lengthier evacuation time ($OR = 2.76$, 95% CI = 1.61–4.74, $p < 0.001$).

Organizational factors

We examined the relationship between full length of time and safety climate for each tower individually as Port Authority employees were headquartered in WTC 1. For WTC 2 respondents, after controlling for disability, prior military, police, fire or security experience, Port Authority

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employment, and fire safety team membership in addition to starting floor and elevator use, respondents with higher scores on the *Emergency Preparedness Safety Climate Scale* were over twice as likely to evacuate more quickly than those with lower scores ($OR = 2.28$, 95% $CI = 1.05–4.96$, $p < 0.04$). No relationship between safety climate and full length of time was noted for WTC 1.

Scores on the *Disability Preparedness Scale* were not associated with length of time to fully evacuate.

Structural factors

Participants who reported two or more adverse structural conditions (i.e. poor lighting, overcrowding, smoke or dust, fire/intense heat, water, debris, doors that would not open, poor/missing/confusing signage, or other) were nearly five times more likely to have lengthier evacuation times ($OR = 4.61$, 95% $CI = 3.12–6.80$, $p < 0.001$). In particular, structural damage or debris was associated with longer full evacuation time ($OR = 4.61$, 95% $CI = 3.12–6.80$, $p < 0.001$).

DISCUSSION

These data, although finely detailed, also paint a broader picture of the evacuees' collective experiences and responses on 9/11. While it is clear that individual-level factors significantly impacted initiation and full evacuation times, organizational and structural factors were also influential in that regard, as depicted in Figure 4. Therefore, we feel that the results of our study support a multilevel approach to emergency preparedness. However, when we consider the overall outcome

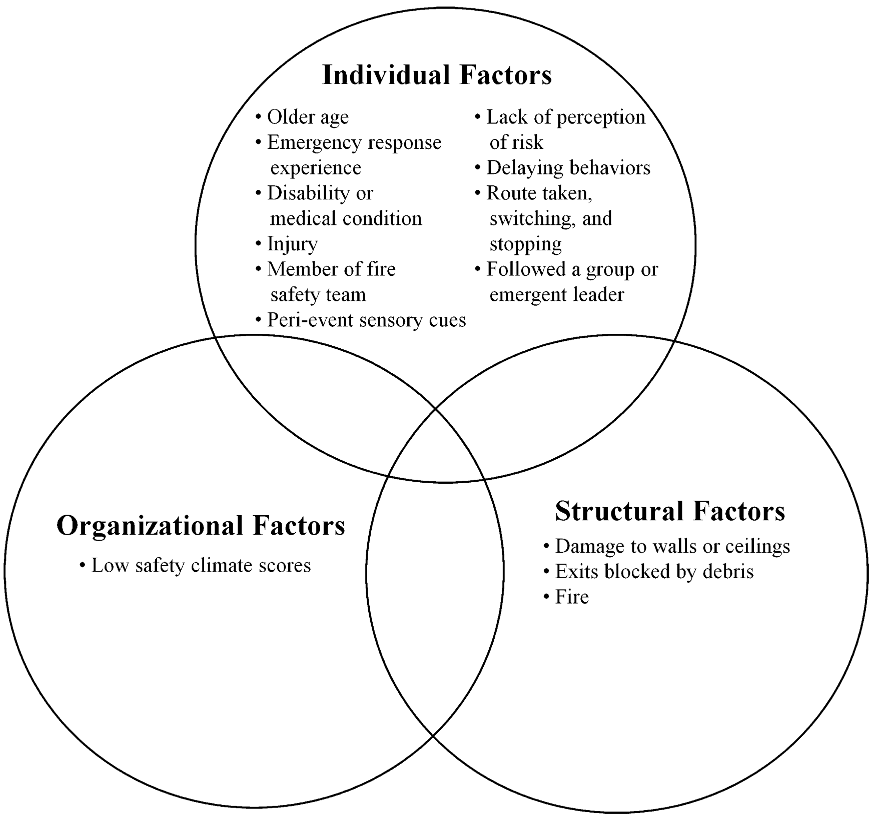

Figure 4. Factors associated with time delays.

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of the evacuation that day, one of the major observations that can be made is that the integrity and resiliency of the physical structure led to generally navigable egress routes. Except in the most immediate floors to the zone of impact, and excepting the extreme conditions at or above the point of impact in the two towers, the fire egress system supported a rapid evacuation. Undoubtedly, other non-disaster-related factors, such as the time of day WTC 1 was attacked, played a role in facilitating the rapid egress. According to NIST estimates, had the buildings been fully occupied, with a full occupant load plus visitors, there would have been more than 20 000 people in each building [1]. Overcrowding in the stairwells would have been inevitable, and undoubtedly, given the extremely limited time to collapse, especially in WTC 2, many more deaths would have resulted [1].

Another broader observation that can be made from our study was that there was a widespread lack of familiarity and knowledge of the building, including the fire safety features of the building and the evacuation plan and procedures. Combined with the extremely low scores on the safety climate scale, this suggests a general lack of organizational support for the emergency preparedness and response capabilities of *all* occupants. After the 1993 bombing, the PANYNJ instituted a fire safety structure and training plan focused on a fire warden and fire team system. This appears to have resulted in a subset of occupants with increased knowledge and familiarity. These individuals were more likely to delay initiation and to have longer full evacuation times, and this was probably related to their taking over leadership and guidance roles. Undoubtedly, their actions helped many others to evacuate. However, our findings indicate that even on the most basic safety elements (e.g. number of fire stairs) the overall knowledge in the general population was lacking.

How might we explain the low scores on all three preparedness-related scales given the expanded fire safety program implemented after the 1993 disaster? Undoubtedly, the complexity inherent in high-rise management structures could lead to organizational gaps. In high-rise occupancies, with multiple leaseholders, managing agents, owners, and many occupants, the management and responsibility for safety can be everywhere—and nowhere. Under U.S. (federal) OSHA, the employer has specific responsibilities for the emergency preparedness of the workplace. However, under local fire safety codes (e.g. 3 RCNY Ÿ602 and 3 RCNY Ÿ908), the responsibility for fire safety generally rests with the building owner, who usually delegates this to the managing director [24, 25]. In NYC, well trained and experienced (and certified) Emergency Action Plan Directors (usually hired by the building manager or owner) have ultimate and immediate responsibility for emergencies. It should also be pointed out that in many high-rise buildings, large individual leaseholders hire their own fire safety director. In truth, this is a *shared* responsibility, including occupants as well. Nevertheless, in terms of preparing emergency plans, policies, and providing training, our findings support the idea that a unified structure, with clear lines of responsibility would be most desirable. A single authority could provide oversight to ensure that no gaps exist and that all policies and practices within the building are consistent. Many high-rise occupancies take this approach, but many do not, especially mid- and low-range high-rise buildings.

We feel that our data support the need to adequately prepare *all* occupants. While some high-rise emergencies, such as the 1995 Murrah Building bombing in Oklahoma, essentially result in rescue operations, many other types of emergencies require the cooperation of all occupants of the building. Having a well-trained and knowledgeable cadre of occupants can shorten the time needed for all occupants to evacuate, which makes wide-spread training so important. Given the high turnover of the workforce in the U.S. and elsewhere, and in consideration of the fact that the workforce is increasingly working, at least part of the time, off-site, it seems reasonable to assume that relying solely on floor wardens and fire safety teams to evacuate buildings with hundreds, if not thousands, of occupants will no longer be sufficient. Through effective training on evacuation procedures, each individual can take on a greater level of personal responsibility, thus aiding the group as a whole.

Our results further provide some directions on the issue of training. Even individual-level risk factors (e.g. delaying behaviors) may be most easily addressed through organizational interventions, including training. For example, while pre-9/11 fire drills were *mandatory* for all occupants (with some exceptions for essential services), 80% had attended one or more drills during their tenure in

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the Towers, and 60% in the past 12 months. However, only very few reported entering a stairwell during drills. In fact, until 2005, this was not permissible under NYC codes due to concerns about injuries and lawsuits [24]. Fortunately this is no longer illegal in NYC and elsewhere. Drills should be thorough and held frequently and at off-hours to be able to accommodate almost all occupants' needs. The increasing introduction of web-based simulation may have utility here—but to our knowledge, this has not yet been well studied in terms of effectiveness.

The training should include building familiarity, and not just of the building itself, but the surrounding neighborhood as well. Providing a sense of the *scale* and dimensions of the building through guided walk-throughs may be especially helpful in terms of addressing a particularly striking finding we noted in our qualitative findings. Many of the people we interviewed reported that they really had *no idea* of actually how far they were from safety. Since most participants had never timed their stair travel time, they did not realize just how lengthy this could be. Even though high-rise occupants are working (or living) in a vertical structure, it is interesting to keep in mind that for many of them, their physical space may still be perceived as *horizontal*. This has implications for training. While it is tempting to suggest that this level of occupant training be limited to certain buildings (i.e. those with iconic stature (such as the WTC), governmental buildings, or national heritage sites, etc.), having every high-rise building better prepared to effect a full evacuation will be the most conservative approach and one that we advocate.

The recommendations to enhance employee training may however result in lost productivity of the workforce, but this must be considered as an undeniable cost of business, as with any other essential overhead cost. A list of training recommendations and other interventions is provided in Table III. As can be noted, there is a large emphasis on employee engagement [26]. The PAR teams in our study felt strongly that employee involvement would best be supported through organizational commitment to safety (i.e. safety culture) [17]. We feel our data strongly support the development of a strong safety culture. This is especially important to ensure the safe evacuation of persons with disabilities and other medical conditions—even acute ones. That many disabled

Table III. Recommendations for high-rise evacuation improvement*.

Organizational Strategies for Improvement
• Link all communication sources to one main broadcast site (with off-site back-up)
• Limit non-emergency PA announcements to only those that are necessary
• Link company computers to television stations, emergency broadcast announcements (e.g. NYC Office of Emergency Management)
• Provide wireless cellular telephones for the safety team members
• Institute system to rapidly identify those who will require special assistance for evacuation
• Pre-plan for persons with disabilities
• Create policies and procedures that ensure confidentiality of disability-related information
• Perform evacuation drills for persons with special evacuation needs, including situations in which elevator does not function
• Ensure mandatory compliance with training and drills
• Enforce training and education of all employees for evacuation
• Enforce mandatory drills that involve entry into the staircase and various routes for terminal egress
• Mark the exit doors so that their location (e.g. N, S, E, W) is clear to help orient employees
• Posting of signage that indicates where staircases terminate
• Install photoluminescent paint
• Sponsor frequent walk-throughs of the building to familiarize all occupants with building layout
Individual Strategies for Improvement
• Individuals should conduct self-assessment of their capability and time needed to fully evacuate
• Individuals should inform the building's safety personnel of any special evacuation needs
• Participate fully in any emergency preparedness training
• Maintain an emergency 'go bag' at desk (including sensible shoes)
• Delay calls until completely exited
• Take ownership of personal safety actions (i.e. act proactively)
• Wear sensible footwear that will facilitate rapid evacuation

*Table adapted from Gershon *et al*. [26].

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individuals were brought to a holding area where they most likely perished in Tower 1 prior to the building collapse, accompanied by, in many cases, their co-workers or others who attempted to assist them, is testimony to the importance of creating evacuation teams (with redundancies) to assist these individuals in completely evacuating high-rise buildings.

When we compare our results to other 9/11 studies, not surprisingly, our quantitative findings are similar. For example, the demographic makeup of the NIST and WTCES study populations was generally alike in terms of age (NIST mean age = 45 years; WTCES mean age = 44 years), gender (NIST: 65% male in WTC 1, 69% male in WTC 2; WTCES: 58% male in WTC 1 and 2 combined), and tenure (NIST: 5.6–5.9 years; WTCES: 6.1 years). The samples did differ on the proportion reporting a disability; 6% of the NIST sample reported a medical condition, whereas 23% of the WTCES sample reported a disability or medical condition. It may be that the WTCES survey items were more inclusive of capturing all possible health problems, or there may have been response-related bias that was inadvertently introduced in our study, which was not randomized for subject selection. On factors associated with evacuation (e.g. cues, information seeking, delaying activities, etc.), the two studies are also very similar. On the important time-related outcomes, the two studies were remarkably similar. For example, in the NIST study, evacuees initiated between 4.2 and 7.4 min after impact, depending on floor zone and building. In the WTCES, they initiated on an average within 6 min. For total time taken to fully evacuate, the NIST study participants reported mean times of 42 min (WTC 1) and 25 min (WTC 2). In the WTCES, the mean times were 40 min (WTC 1) and 22 min (WTC 2). When we estimated the rate per floor (controlling for floor zone and elevator use), our rates were 60 s per floor (WTC 1) and 30 s per floor (WTC 2), and we believe that these rates are also consistent with the NIST data.

Our findings also support the results of Kuligowski and Mileti's based on their modeling of NIST data on pre-evacuation delay. Using the path analysis, they were able to identify factors that we similarly found in the WCES study [27]. They conclude that theories on community evacuation have applicability for high-rise evacuation in terms of human behavior. We agree with this assessment, as cues, proximity to exits, information seeking, perceived risk, and delaying activities—which are all known to be important factors in terms of initiation response to almost any emergency—also held true in the WTCES sample.

Our findings are also demographically similar to the HEED study sample of 254 evacuees [28]. We also had generally similar findings to HEED data in terms of stoppage data and peri-event behaviors. Their initiation times and stair travel times published in this issue appear to be relatively similar to our estimates, although our measurement variables were different—making direct comparisons difficult. Nevertheless, there are reassuring commonalities notwithstanding the differences in methodology, measures, and statistical analysis across all three major studies.

When we compare our findings to studies on the 1993 WTC bombing conducted by Proulx and Fahy, we find that while the median initiation times for both 1993 and 2001 were similar, in 1993, WTC 1 occupants delayed initiating for as long as four hours and the length of time taken to fully evacuate both towers was much longer than 2001 data [29]. Delays in total time to evacuate in 1993 were attributed in part to ambiguous cues, which many 2001 occupants also reported. In both studies, this ambiguity undoubtedly led to information seeking or, for some individuals, to start evacuating, and both types of responses have been shown in other studies that have explored the role of cues in the assessment of risk [12, 30]. Proulx and Fahy note that the 2001 evacuation benefited greatly by improvements that were implemented after the 1993 bombing, and we concur, as the length of time to full evacuation was dramatically shortened, probably because of the improvements in the stairwells and specialized training of fire safety team members [9, 29].

We also note that our results are similar to Aguirre *et al.*'s findings in their 1993 study [4]. For example, they found (in an interactive model) that people who perceived more danger were likely to initiate evacuation earlier than those that did not, a finding that we also noted. Aguirre *et al.* also found that this was mitigated by the size of the group—large and familiar groups were slower, even if individuals in the group perceived greater danger. The authors concluded that this effect, as predicted by the Emergent Norm Theory, [31] highlighted the importance of prosocial behavior. Other researchers have also found that pre-existing social relationships result in evacuation delays,

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as individualistic behaviors are inhibited in deference to group norms and prosocial behaviors [32]. We similarly noted in our study that initiation times were lengthened for evacuees who reported leaving in large groups.

Finally, although we did not specifically focus on design issues of the towers themselves, we feel that our data suggest certain features that may be helpful in effecting full evacuation of high-rises. Specifically, high-rise structures should simplify, wherever possible, the way-finding of occupants. Paths should be as intuitive as possible, with as few deviations as possible. The availability of extra wide staircases for emergency responders, slow movers, etc. would be especially helpful. Within the stairwells, we were informed by qualitative phase participants, that the photoluminescent paint, which was installed after the 1993 bombing, was especially helpful. This has now been codified for all NYC high-rise business occupancies and many other jurisdictions have likewise adapted this structural intervention [33].

LIMITATIONS

A number of study limitations are acknowledged. First, and most importantly, was the lack of randomization of the sample. Although we attempted to randomize the selection, starting with the Port Authority badge list, we ultimately also recruited a convenience sample of WTC 1 and 2 occupants from the NYC Department of Health and Mental Hygiene WTC Health Registry. Additionally, other participants entered the study though our website. However, when we compare our sample's demographic composition to NIST, the NYC DOH registry, and available demographic data from the five largest WTC 1 and 2 leaseholders, all samples are quite similar. There is also inherent survivor bias of our sample. Our study was not conducted to identify occupant differences that may have impacted survivability (e.g. health status of decedents below the point of impact compared to health status of evacuees). A study of that nature requires a case control design and a forensic epidemiologic approach, which was not part of our scope of work. Our cross-sectional design, while limited in some respects, was suitable for observing associations between risk factors and the major outcome variables.

Another potential limitation was that participants might have provided socially desirable responses, although the anonymous nature of the questionnaire may have allayed their concerns in this regard. We must also acknowledge the potential for recall bias; participants completed the questionnaire about 24 months after the event. However, the use of the timeline prompt may have helped. Also, virtually all respondents in out qualitative phase stated that the events of that day were indelibly etched upon their memories as a life-changing event. We feel that the sample size, the generalizability to the full population, the validation of findings with our qualitative data, and similarities to the other major studies in terms of outcomes help support the overall validity of our findings.

CONCLUSIONS

Our findings, along with the results of the two other major WTC evacuation papers (namely data from the NIST and HEED studies published in this issue) underscore not only the potential vulnerabilities of high-rise occupancies, but also the important role of emergency preparedness in mitigating these. While we can readily appreciate that the buildings' resilient structures played a major role in supporting evacuation on 9/11, we also note the important role of human behavior and organizational preparedness. Worksite readiness is essential, not only in reducing morbidity and mortality related to emergency events, but also for creating a culture and climate of emergency preparedness. These is also a growing body of evidence that this type of culture can support worker resiliency and help reduce long-term mental health consequences of disaster survivorship. Furthermore, a culture and climate of preparedness may empower employees to take responsibility for their own actions. By understanding their role in supporting the safety of the entire population of occupants, employees may be more likely to ensure that they are personally as well prepared

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as feasibly possible. From our study, we saw signs of this in terms of participants' eagerness to maintain a façade of calmness—even if they did not actually feel this way. The importance and saliency of worksite preparedness and developing and inculcating a culture of preparedness cannot be overstated, given the hazards we increasingly face. Natural and man-made disasters will continue to occur, more local emergencies will inevitably take place, and our need to effectively respond will continue. Hopefully, the invaluable input of the WTC disaster survivors and many others who were involved in these and other studies will help support further improvements in high-rise safety.

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