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The behaviour and evacuation experiences of WTC 9/11 evacuees with self-designated mobility impairments

T.J. Shields [a], K.E. Boyce [a,*], N. McConnell [b,1]

[a] School of the Built Environment, University of Ulster, Shore Road, Newtownabbey, Co. Antrim BT37 0QB, UK
[b] Queen's University Belfast, University Road, Belfast BT7 1NN, UK

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ABSTRACT

The increasing accessibility of buildings to people with disabilities requires that buildings are also designed and managed to provide accessible means of escape for all. In so doing, it is important to understand the capabilities of building occupants with disabilities to evacuate and their interaction with others. This is particularly important in high-rise buildings where occupants' primary means of accessing upper floors, i.e. lifts, may not necessarily be the preferred route in a fire emergency.

Until recently there has been little in-depth study of the evacuation of mixed ability populations in a large-scale emergency building evacuation. The evacuation of the World Trade Centre (WTC) on September 11, 2001 was one of the most significant evacuations of high-rise buildings in modern times. The UK High-rise Evacuation Evaluation Database (HEED) study aimed to capture the detailed and multifaceted behaviour and experiences of the evacuees in a relational database which would facilitate the answering of research questions relating to the evacuation of high-rise buildings, including questions relating to the evacuation of people with disabilities. The information stored in the HEED comprises pre-interview questionnaires, interview transcripts and coded time, location and experience data on 271 persons who evacuated the World Trade Centre on 9/11. This paper focuses on the behaviour and experiences of six evacuees of Towers 1 and 2, who declared a mobility impairment in their pre-interview questionnaire. The individuals' physical and medical profiles, together with their fire safety awareness profiles, as determined from the pre-interview questionnaire, free flow and semi-structured interviews are presented, together with details of their experiences as they evacuated the towers. Their need for assistance, formation of groups with their assistors or others, perception of risk and the difficulties or otherwise that they encountered are also considered. Issues with respect to a definition of disability for fire evacuation planning/design, sufficiency of escape route widths, group behaviour, nature/delivery of training programmes and emergency preparedness are discussed.

1. Introduction

There has been interest in the evacuation of people from buildings in fire and other emergencies since the early 1900s [1]. Serious academic interest in the subject emerged in the 1950s through the seminal efforts of Bryan [2], while the area of study gained more prominence in the 1970s through the works of Wood [3] and Canter [4]. As interest in the topic grew, and a more enlightened approach to the provision of access to and within buildings for people with disabilities followed, the study of human behaviour extended to consider the needs of the people with disabilities, including those with mobility difficulties [5].

Interest in the subject area widened to include consideration of mixed ability populations, management of evacuation, contra-flows in evacuation routes and the recognition and elimination of invalid assumptions [6]. This increase in interest was stimulated by the introduction in the 1980s of mandatory provisions in the collection of United Kingdom building regulations which required non-domestic buildings to be accessible to disabled persons and which in turn focussed attention on provisions for the emergency evacuation of mixed ability populations with particular emphasis on provision of adequate escape from fire [7]. These regulatory changes, rooted in concerns for the health and safety of the occupants of buildings, were underpinned by the introduction of BS 5588 Part 8 Code of Practice for Means of Escape For Disabled People [8], which made recommendations in relation to the design and management of refuge areas in combination with lifts as means of escape from fire for disabled people. In the USA, in 1991, the Department of Justice [9] produced guidelines for the implementation of the Americans with Disabilities Act which

* Corresponding author. Tel.: +44 0 2890 368703; fax: +44 0 2890 368726.
E-mail addresses: ke.boyce@ulster.ac.uk (K.E. Boyce), n.mcconnell@qub.ac.uk (N. McConnell).
[1] Tel.: +44 0 2890 245945.

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addressed issues similar to those addressed in BS 5588 Part 8. The focus of attention then was also the potential of refuge areas and lifts/elevators in relation to the life safety potential of people with disabilities in fire [10,11].

In 1993 a Building Research Establishment Report, "Fire and Disabled People in Buildings" [12] was published. It critically analysed the available statistics, and commented on the available knowledge and guidance to designers and fire safety engineers at that time. The report highlighted that much work still needed to be done in order that the behaviour and capabilities of people with disabilities in fire be understood at a level commensurate with the behaviour of, what might be termed, able-bodied people in fire.

Throughout the 1990, symposia and workshops started to focus more on the issue of human behaviour in fire generally, including the capabilities/needs of persons with disabilities, e.g., CIB W14 Engineering Fire Safety in the Process of Design: Demonstrating Equivalency [13]. In 1998, the First International Symposia on Human Behaviour in Fire [14] was the primer for the Second and Third International Symposia held in 2001 [15] and 2004 [16], respectively, all of which had sessions devoted to persons with disabilities.

As noted previously, much of the early work focussed on wheelchair users, since this group were perceived as presenting the greatest challenge in relation to safe evacuation from buildings. However, many different physical, psychological and medical conditions can impact on a person's ability to evacuate a building; an understanding of the impact, not only the individual's ability to evacuate but also on the entire evacuating population, is important in our understanding of evacuation behaviour and dynamics to inform fire engineering design and modelling.

Studies by Shields [12] and Dunlop and Shields [17], which included evacuations of a hotel, film theatre and museum, highlighted the delicate interaction which occurs within mixed ability populations evacuating buildings. In order to understand the dynamics of evacuation it is important to understand more fully the percentages of the evacuating population who will experience difficulty, whether they are likely to be assisted or not, their capability to travel over long distances, and their need to take rests. The most recent surveys of disability in Great Britain and Northern Ireland, conducted in 1984 and 1989 by the Office of Public Census and Survey (OPCS) and the Policy Planning and Research Unit (PPRU), respectively [18–21], suggested that 13–17.5% of adults had a disability, which included locomotion, seeing, hearing, reaching and stretching/dexterity and mental disabilities. Further analysis of the PPRU data by Boyce et al. [22] provided more detailed estimates of the percentage of the total mobile population in Northern Ireland who had various types of disability. This work suggested that approximately 8% had a locomotion disability with some 4.3% experiencing some difficulty in using stairs. In these surveys the benchmark for having/not having a locomotion disability was 'not being able to walk 400 yards without stopping or severe discomfort'.

Additional experimental work involving people with disabilities [23] provided information on the walking speeds of persons with locomotion disabilities on the horizontal, ramps and stairs. This work suggested that the speeds of persons with locomotion disabilities was on average 0.8 m/s on the horizontal and 0.33 m/s on stairs. These speeds are considerably lower than those of able-bodied persons, which are typically in the region of 1.25 and 0.75 m/s on the horizontal and stairs, respectively [24]. It should also be noted that in this study the stair speeds were measured over one flight of stairs and therefore the speeds that could be sustained over long distances by people with disabilities would be expected to be even lower again.

Shields' studies involving an unannounced evacuation of a hotel [12] and a real evacuation of a museum [17], also raised questions regarding the sufficiency of escape route widths to accommodate mixed ability evacuation. In order to consider the sufficiency of escape stair widths it is necessary to understand, not only the number and spatial density of the occupants, their capabilities to travel, their need for assistance and nature of that assistance but also the space requirements of the individual and assistors. Useful dimensional information distilled from Johnson's studies of assistance techniques [25] has been used by Shields and Boyce [26] to suggest appropriate staircase widths to accommodate different types of assisted evacuation of disabled persons, including ambulant persons assisted by one and two persons. Minimum escape stair widths required for the evacuation of mixed ability populations, depending on whether the evacuations were controlled, i.e. managed properly, or uncontrolled were proposed, i.e. 1000 and 1200 mm, respectively.

The sufficiency of escape stair widths to encourage overtaking of slower evacuees, including assisted disabled evacuees, is an issue not addressed in the design of evacuation routes. For example, it has been shown [27] that the presence of a wheelchair bound evacuee in a stairway during an evacuation slowed the rate of descent of the evacuees and, even though there was physically sufficient width of stair to accommodate overtaking, there was insufficient motivation on behalf of the more physically capable evacuees to do so.

Clearly, from the foregoing, there is much to ponder and somehow distil pragmatic design guidance regarding the provision of adequate and sufficient means of escape for mixed ability populations in buildings. Until recently there has been little in-depth study of the evacuation behaviour of mixed ability populations in a large-scale emergency building evacuation. The World Trade Centre disaster on September 11, 2001, one of the largest full-scale building evacuations of people in modern times, focused attention once again on issues associated with life safety provision in high-rise buildings. High-rise buildings present a particular challenge since evacuees' travel ability can be much impaired depending on the height of the building and the evacuee's location within the building, i.e. increased distances to final exit, and potentially increased need to rest. Indeed, the evacuation of WTC1 and WTC2 in 1993 identified problems associated with the evacuation of mobility-impaired occupants, i.e., their evacuation was described as "slow and arduous" [28]. NIST's study of the 2001 evacuation [29] reported that 51% of the occupants of WTC1 and 33% of the occupants of WTC2 indicated that injured and disabled people in the stairwell were a constraint to evacuation.

The United Kingdom-based study of the evacuation [30–33] provides the opportunity to understand the evacuation of persons with disabilities more fully. This paper will focus on the behaviour and experiences of six people who evacuated Tower 1 and Tower 2, who declared a mobility impairment in their pre-interview questionnaire.

2. Project HEED

The development of a High-rise Evacuation Evaluation Database (HEED) was a project based on the accounts of the survivors from WTC 9/11 Towers 1 and 2 and funded by the United Kingdom Engineering and Physical Science and Research Council (EPSRC—GR/S74201/01 and EP/D507790). It was a collaborative project between the Universities of Greenwich, Ulster and Liverpool to collect and archive the firsthand evacuation experiences of WTC twin towers' evacuees. In essence the research focused on collecting and collating the evacuee evacuation experiences and creating an inter-relational evacuation experiences database which will provide an interactive research environment for

bonafide researchers for years to come. This was achieved by use of one to one interviews, which allowed the team of researchers to elicit and capture data and information relating to, for example, cue recognition, patterns of response, cognitions, leadership, training, perception of risk, stair densities, merging flows, deference and other behaviour.

A detailed account of HEED study methodologies and the recruitment process have been presented by Galea and co-workers [30–33]. In brief it comprised a:

- *Pre-interview questionnaire* designed to extract basic factual information from the participant. This included information related to the participant's sex, age, pre-existing medical health, exercise, whether or not they had a disability on 9/11, how long it had existed and the nature of that disability, whether or not they used physical aids on 9/11 and whether or not they were assisted in their evacuation.
- *Free flow narrative* where each participant was encouraged to recall in their own words the morning of 9/11 and to describe their experiences from the time they entered the WTC towers until they finally exited the towers.
- *Semi-structured interview* which permitted the interviewer to clarify details and elicit more precise information regarding the participant's entire evacuation experience. Given the time lag between the event and the interviews (which took place during extended periods from January 2005 to August 2006) cognitive interview techniques were used to aid participants' recall of the event. During the interview interviewers also attempted to extract information from the participant in relation to the time and location of their described experiences. Where the absolute time that an incident occurred could not be determined, the interviewers attempted to determine the times relative to known times, namely, the impact on WTC1 at 8:47 a.m., the impact on WTC2 at 9:03 a.m., the collapse of WTC2 at 9:59 a.m. and the collapse of WTC1 at 10:28 a.m.
- The participants' perception of risk (rated on a seven point Likert scale) was also determined at key points throughout their evacuation, i.e. at WTC1 impact (or recognition that something unusual was happening, when the participant was deciding to evacuate, when the participant knew that WTC2 had been hit (if applicable) and when the participant knew WTC 2 had collapsed (if applicable).

Participants were recruited mainly from the World Trade Center Health Registry (WTCHR), a voluntary list of individuals who were exposed to the environmental effects of 9/11, compiled by the NYC Department Of Health and Mental Hygiene. Other recruitment methods, e.g. inclusion in parish bulletins in the Archdiocese of Newark and Brooklyn, were also employed. Individuals who wished to take part in the study were invited to register on the project's website (www.wtc-evacuation.com), and complete the web-based Pre-Interview Questionnaire. In total 271 persons were interviewed.

The methodologies outlined above viewed and used separately yield discrete data and related information. However, when integrated, the yield of quality data and information is increased by several orders of magnitude, a distinguishing feature of the data and information retrieval systems used in this research. The resulting HEED database developed using Microsoft (MS) Access, is a flexible interactive research tool which stores and facilitates analysis of data and information distilled from the transcribed interview accounts. HEED encapsulates all of the participants' perceived evacuation experiences such as stimuli (e.g., observational cues), cognitions (e.g., incident interpretations) and individual and group behaviour (e.g., actions and reactions) within a three-level Experience hierarchy [30–33]. In addition to coded transcripts, HEED also includes the full transcripts for each interviewed participant and the pre-interview questionnaire responses. These transcripts and pre-interview questionnaires form the basis of the analysis and discussion in this paper.

3. The sample

In the study reported in this paper 6 of the 271 persons interviewed, i.e. 5 from Tower 1 and one from Tower 2 declared a mobility disability in their pre-interview questionnaire. These figures seem relatively small, given that NIST, in their study [29], reported that 6% of those interviewed had a limitation that impacted their ability to evacuate. However it should be noted that the NIST figure included all factors that were considered to impact evacuation, including recent surgery, injury, obesity, heart condition, asthma, being elderly and pregnancy, i.e. not necessarily conditions that would be described by the individual themselves as a 'mobility impairment'.

3.1. Participant physical and medical profiles

As noted previously, the pre-interview questionnaires, administered to participants prior to interview, provided information in relation to demographics, as well as whether or not they had a disability or medical condition, physical activities undertaken on a regular basis and whether or not they used physical aids and needed assistance to evacuate on 9/11. It is important to note that the data obtained from the pre-interview questionnaires enabled only partial profiles of the participants to be developed; other important information was gleaned from the free flow narrative and the semi-structured interviews. The physical/medical data obtained from the pre-interview questionnaire, and additional information obtained from the free flow narratives and semi-structured interviews, of the self-designated mobility-impaired WTC evacuees are given in Table 1.

Table 1 includes information on the participants' (A–F) age, gender, body size, weight and fitness at the time of the event. It also includes information on physical exercise undertaken by participants, in terms of activity and frequency, which together can be taken as an indicator of their general levels of fitness at that time. From Table 1 it can be seen that only participant E was unable to engage in general physical activities, whilst at the other end of the spectrum, participant C jogged 5 days per week for a least 30 min, participant D walked 7 days per week and participant F, despite having limited use of his left leg, i.e. left leg paralysed, played sports, used the gym and walked. Table 1 also provides information on the length of time participants had a mobility impairment, which ranged from (temporary) 1 month to (permanent) 15 years. In addition to mobility impairments, participants had various medical conditions (some more than one), commonly hypertension. Only participant E used mobility aids on a regular basis; participant C's use of crutches and an air cast ankle support is significant but temporary.

As Table 1 shows, the data obtained from the pre-interview questionnaires, supplemented with information distilled from the free flow narratives and semi-structured interviews, generates more complete and useful participant physical and medical profiles. Taking each participant in turn:

- Participant A had knee surgery and his knee got stiff when he was walking downstairs.
- Participant B walked to work and up and down at least one flight of stairs, i.e. no obvious mobility impairment.

Table 1
Mobility-impaired evacuee/physical and medical profile.

Participant	Gender (M/F)	Age (yr)	Height (ft and in)	Weight (lbs)	No. of days/ week of 30 min moderate physical activity	Type of physical activity	Length of time with mobility impairment (yr)	Smoker yes/no and no. cigarettes/ day	Medical condition and duration of time (yr)	Nature of mobility impairment/ constraint	Location (tower and floor)	Physical aid used in evacuation	Physical assistance given to others in evacuation Yes/No	Type of physical assistance given to others	Physical assistance from others in evacuation Yes/No
A	F	61	5′3″	180	1	Walking	3	No	Not given	[a]Knee surgery—no pain. [a]Knee stiff—had trouble when walking down stairs	WTC1 64	None	No		No
B	M	50	5′10″	250	5	Walking	7	No	Hypertension (9)	[a]Not obvious—walked to work.	WTC1 63	None	Yes	[a]Completed circuits chasing/ ushering co-workers off the floor.	No
C	M	49	6′1″	195	5	Jogging	1 mth	Not given	Not given	[a]Severely sprained ankle—*'I could hardly walk'*. Used crutches and air cast. Could not walk too far. [a]Took off shoe at work station.	WTC1 54	None	No		No
D	F	50	5′4″	200	7	Walking	15	No	Hypertension (15) Diabetes (25) Heart condition (18) [a]Sciatica (0) [a]Hyster-ectomy (0)	[a]*'Sciatica slows me down'*. [a]Still suffered pain from hysterectomy.	WTC1 17	None	No		No
E	F	54	5′8″	250	0	None	6	No	Hypertension (5) Severe arthritis (6)	[a]Severe arthritis. Knee surgery. Severe pain some days. [a]Utilised aids for short distances and POV/scooter for longer distances. [a]Used secretary's chair (wheeled) to move around office.	WTC1 20	Stick/ cane/ crutches	None	[a]Waited with protectors and calmed them.	Yes [a]Used cage of people, i.e. co-workers were positioned behind, in front and to the outside of 'E'.
F	M	48	6.2	225	7	Walking Gym Playing sports	25	Yes 3–9	Hypertension (25)	[a]Limited use of left leg. [a]Left leg paralysed.	WTC2 79	None	Yes	None	No

[a] Information collated from the free narrative/semi-structured interview.

- Participant C had a temporary impairment, i.e. a severely sprained ankle so bad in fact that he could not walk to work. He used crutches to get around and wore an air cast for support which he removed when at his work station. He also removed his shoe for comfort when at his work station.
- Participant D had many medical and physical ailments. She endured pain from previous surgery (hysterectomy) and had sciatica (a form of back pain that affects the lower half of the body) which in her words 'slowed me down'.
- Participant E had knee surgery and severe arthritis. She could only walk short distances using sticks or canes and used a POV/scooter for longer distances. She wheeled herself in her secretary's chair to get around the office.
- Participant F, although physically very active, was paralysed in his left leg and suffered from hypertension.

3.2. Participants' fire safety awareness profiles

In addition to the participants' physical and medical profiles, information on their awareness of fire and evacuation procedures was sought and obtained, as this information might provide insights into their likely behaviour in a fire-related emergency. Data obtained from the participants' pre-interview questionnaires, supplemented with information distilled from their free flow narratives and semi-structured interviews, are presented in Table 2.

From Table 2 it is clear that all of the participants had worked in WTC for some considerable time; only one of them (participant F) had a designated fire safety role or responsibility; all had participated in fire drills in the year prior to the evacuation. However, none of them used the stairways as part of a normal or regular route and, interestingly, none of them knew the areas into which the stairwells would discharge if they had to use them. In effect, the basic training they received was delivered by way of participation in drills, which consisted of walking to a stairwell lobby, but not entering the stairwell itself.

Adding the information distilled from the free flow narratives and semi-structured interviews to that given in the pre-interview questionnaires creates more complete participant fire safety awareness profiles. Taking each participant in turn:

- Participant A had evacuated the building in the 1993 incident; following 1993 she had equipped herself with a flashlight, which she had with her during the 9/11 evacuation. She was able to relate to her 1993 evacuation experience, was aware of the existence of fire safety wardens and who they were and also knew that they were not in on 9/11.
- Participant B was critical of the nature of the drills. Notwithstanding, having also evacuated the building in 1993, he subsequently carried what he termed a "*relatively small emergency back pack*" (rucksack), which he had "*meticulously and methodically prepared*". It contained chemical lights, a mini-meg flash light, a length of rope, a survival knife, and "*other different kinds of equipment*". He was self-reliant and independent and had understanding of fire, i.e. he felt the fire doors on the stairway landings to see if they were hot.
- Participant C was not involved in the 1993 evacuation and, although he was aware of the location of 3 stairwells, he had never been in any of the stairwells.
- Participant D felt that the fire safety training delivered, i.e. drills were lacking, i.e. she could not see the exits because of the crowding so she familiarised herself with the exits; to quote "*I wanted to be able to get out of the place*".
- Participant E had participated in disaster training scenarios related to her nursing profession; as night supervisor in a nursing home she had evacuated occupants from fire. She had also made her children fire safety aware and had evacuated WTC2 in a fire incident prior to 9/11. She knew about the hazards associated with elevator evacuation and could rationalise, analyse and synthesise situations for herself. Despite these claims, she allegedly had no personal evacuation plan, to quote "*I never thought of me*".
- Participant F had evacuated WTC in 1993 and as a floor warden he was a member of his organisation's safety team with a specific fire safety role. Prior to working at WTC he received training as a bodyguard and as he succinctly put it "*you do what you gotta do*".

4. Participants' response behaviour and experiences during the evacuation of WTC 9/11

The sets of informational profiles for the participants set out in Tables 1 and 2, and the foregoing elaborations, provide a contextual framework for analysis of their respective behaviour and experiences during their evacuations of WTC 9/11 Towers 1 and 2. A detailed analysis of the process of evacuation for each participant through the various phases, i.e. horizontal evacuation of the floor, vertical evacuation and exiting the building, was conducted. An example of the output from this detailed process of analysis for participant A is given in Tables 3–5. The tables are supplemented by the commentary in the following paragraphs with respect to each participant.

4.1. Participant A

Participant A was located on the 64th Floor of WTC1. Her responses, actions, observations and time lapse to begin evacuating from her location from the time of impact at 8.47 a.m. is summarised in Table 3. Table 4 summarises her experiences, actions, information received, etc. during her vertical evacuation of WTC1 and Table 5 likewise summarises her experiences exiting the building from the mezzanine floor level.

As noted previously, participant A had experienced the evacuation of WTC in 1993, was prepared for evacuation in that she had carried on her person a flashlight and knew about the absence of the fire safety wardens. However, in the early stages, she did seek information or confirmation from co-workers and, despite being on the 64th floor, did not apparently feel any urgency to evacuate. She explained this by the fact that in the 1993 incident "*they stayed put quite a while*". At this juncture participant A scored her perception of risk as moderate. However as time passed more urgency in activity is apparent, i.e. she ran around to the middle stairway following others. She did not delay to phone or prepare for evacuation. When she decided to go she went directly and estimates that she evacuated the floor in less than 5 min.

Participant A had knee surgery and experienced some discomfort, if not difficulty, negotiating stairs. On her descent (see Table 4) she used the handrail for support; the stairwell was not crowded initially and she moved down at normal walking pace. When she transferred at floor 44 to the narrower stairway, conditions were more crowded and merging flows were experienced. At floor 29 she and the other evacuees around her deferred to the upcoming fire fighters and the pace of descent slowed; it also slowed when she encountered water at about floor 6.

Table 5 summarises participant A's experiences exiting the building from the mezzanine level. Interestingly, upward moving escalators were used to move people up onto the mezzanine level from which she exited the building at approximately 9.40 a.m.

Table 2
Mobility-impaired evacuee fire safety awareness profile.

Participant	Number of stairwell locations known before 9/11/used as part of regular route (Yes/No)	How long worked WTC1 (yr)	Number of people managed/ supervised	How many fire drills participated in year prior to 9/11 (no.)	Fire drill consisted of:	Evacuated WTC in 1993	Evacuated from any building prior to 9/11	Other relevant information,
A	3 (No)	6–10	0	2	Walking across floor to stairwell entrance but not descending stairs.	Yes	No	[a]Was aware that fire wardens were not in. [a]Carried flashlight since 1993 for safety reasons—"*I'll be able to get out of this place*". [a]Knew where stairwells would lead to.
B	3 (No)	2–5	0	2	Walking evacuation route up to door to stairwell. [a]Alarm would sound—people would stand in the hallway. Not made aware of fire exit doors or shown crossovers. Not told where the stairwells led to. Fire phone was in hallway but locked.	Yes	No	[a]Was fire aware—felt fire doors on landings with back of hand to see if they were hot—would stop anyone trying to open hot door. "*You can't rely on life safety people and retired fire battalion chiefs who run a fire drill once every 6 months or so. You have to look after yourself*". Military training and conditioning thought long gone took over. [a]Following 1993—carried a "safety" back pack with emergency items, e.g., lights, rope and knife. [a]Sometimes he would ignore fire drills and hide in the men's room. [a]Knew which was the widest stair but did not know where stairwells would lead to.
C	3 (No)	11–15	<30	2	[a]WTC would conduct 3 drills. Would go where were supposed to go and stand/wait for the all clear.	No	No	[a]Noted that organisation worked for was not always focussed even after 1993 on getting people out of the building in the event of a catastrophe. [a]Recognised need for disaster recovery plan after 93.
E	2 (No)	2–5	0	2	Walking evacuation route to stairwell entrance. [a]All went out into hall and drank coffee. Stood around listened to what was said and went back to work.	No	[a]3 weeks before 9/11 had been involved in incident on floor in WTC2. Fire trucks arrived outside. Was scared. Saw firemen coming up the elevator, so thought "if they can come up I can go down in elevator". [a]Was a night supervisor during a nursing home fire from which she evacuated people horizontally.	[a]Had never been in the stairwell [a]Played games with children in different settings—What if there was a fire? [a]Claimed had never thought of herself and did not have a personal evacuation plan. [a]Remembered training which suggested not to use elevators during fires. [a]Used cane to walk hallway during drills as it was too crowded for POV/scooter.
F	3 (No)	2–5	<10	4	[a]Walking evacuation route to a door to a stairwell.	Yes	No	[a]As a nurse participated in many disaster training scenarios. Was a floor warden. [a]Was trained prior to being there, i.e. was a bodyguard.

Table 3
Participant A's responses, actions, observations and time delay to evacuation of floor from WTC1 impact at 8.47 a.m.

Participant	Floor	Position	Activity	1st cue	Response	Information received from/given to co-workers	Observations	Decisions	Actions	Evacuation	Observations/ comments
A	64	South/ east corner	Standing up facing window.	*"Building violently swaying back and forth twice. Saw debris falling down".*	Grabbed filing cabinet. Thought it was window cleaner's trolley. Incomprehensible. Stood there, nobody did anything. Went round corner to get information from 15 to 20 co-workers. Didn't feel any urgency.	Some leaving building. Kitchen cabinets coming off walls. *"It has to be a plane nothing connected at this time".*	Some people leaving. Others standing around. Saw man with woman who was totally frozen in fear.	*"We all decided to leave. My motivation was to leave".*	They went straight ahead. *"I went back to my desk. Did not: phone, put on sneakers or go to bathroom".*	Left after 3–4 min, not more than 5 min. Behind others to get to stairwell. Went out south/east door/ stairwell right there. Followed others then ran around to middle stairwell and left floor.	Trained to use nearest stairwell. Followed other co-workers running to middle stairwell.

Table 4
Participant A's experiences, information received, actions and comments re vertical evacuation WTC1.

Participant	Floor	Location	Action	Observations	Vertical evacuation interruption	Observations	Actions	Contra-flow experiences	Information received/given to others	Actions	Observations/ comments
A	64	Standing stairwell B landing	Descend stair using handrail. *"Going down little slower than used to be".*	*"Stairwell not crowded. Walking normal pace. Co-workers about a flight and a half ahead".*	Diverted by World Trade Department personnel maintenance at 44th floor (transfer corridor) to south/east stairwell, i.e., the one nearest her workplace.	Transfer door at 44 held open. Moved faster across transfer floor. Not many people on 44 backlog at south/east stairwell little more crowded. Smaller stairwell. *"People merging from other floors. Mingling with people from 71st floor".*	Walked downstairs. *"Easy walking".*	Floor 29 approx. met firemen coming up. *"Everybody stopped, stood aside to let firemen up. Automatic action after they had gone past there was space ahead for a floor or two. We spread out a little and walked down".*	Floor 6, people saying floors wet. Put shoes back on. *"Medical people saying triage office on floor 6 if it was needed".*	Continued down.	Pace slowed when met fireman on way up and hit water on floor at about floor 6.

Table 5
Participant A's actions, information received and observations from existing stairwell at mezzanine floor to final exit.

Participant	Location	Action	Information/directions received/given to others	Action	Observations/comments
A	Mezzanine south/east stairwell nine	Entering mezzanine floor	Directed down stationary escalator to concourse level, through concourse, to upward moving escalator away from Plaza level. Police advised of injured to go towards ambulance, *"if not get out as fast as you can; go north or east"*.	Moved quickly across mezzanine floor. *"I was focussed on getting out"*. Exited building in about 1 h from starting off. *"I was out at about 9.40 am"*. Got out fast went east to get train.	At concourse level all shops closed, all gates down, sprinklers on, got soaked.

From the foregoing it is clear that participant A evacuated without too much difficulty. Clearly her preparedness for coping with emergencies and subsequent actions were influenced by her experience of the 1993 evacuation of WTC. She evacuated the floor in less than 5 min and exited the building around 9.40 a.m. Assuming that she entered the stair at 8:52 a.m., we arrive at an estimated rate of vertical descent of approximately 1.3 floors/min. This descent rate was achieved despite a knee stiff from recent surgery, merging flows, deference behaviour towards fire fighters and encountering water at around floor 6.

4.2. Participant B

Participant B was located on the 63rd Floor of WTC1. As noted previously, it is clear that participant B was very fire safety conscious; he had evacuated WTC in 1993 and subsequently carried a survival backpack. Analysis of his experiences suggests that he heard the scream of jet engines, saw falling jet engines and other debris and knew a plane had hit the building. He noted that at this time others were eating, unplugging equipment but he decided to get out. He yelled at others to get out, herding people towards an exit and ignoring the suggestion of co-workers to look for others. Participant B scored his perception of risk as very high at this time. He estimates that he entered the stairwell some 12 min after the time of impact, i.e. some minutes before 9.00 a.m. Notwithstanding participant B's preparedness for evacuation and awareness of the situation, he spent quite some time evacuating others off floor 63 but felt sufficiently in control of himself to know when, in his judgement, it was time for him to go.

On entering the stairs participant B joined the tail of the flow descending stairwell B and descended at what he described as a brisk pace until upcoming fire fighters were encountered. At that time the flow became staccato, i.e. stopping and starting. Merging flows were also experienced and propped open landing doors were observed. Participant B provides fairly graphic descriptions of his contacts with the fire fighters with a line of 10 or 12 moving up in single file. This is contrary to suggestions that fire fighters went up in small groups of 4 or 5. On the way down participant B checked the landing doors to see if they were hot, i.e. he was monitoring the situation as he understood the hazards associated with fire. He noted that the landings were big enough to allow people to squeeze to the side to allow injured people to pass. At around floor 10 he slipped and fell but in his own words *"got right back up and continued"*.

Participant B again noted the use of escalators as a means of escape and likened the scene at the concourse level to a science fiction movie; this captures vividly the incredulity of the evacuees.

Much happened and was experienced by participant B in his evacuation of WTC1 yet, despite a 12 min delay in starting to evacuate, an undefined mobility impairment, staccato descent flows on the stairs and falling once on the way down, he reported being outside Saint Paul's Chapel across the street at 9.45 a.m. This equates to a descent rate of approximately 1.4 floors/min.

4.3. Participant C

Participant C was located on the 54th floor of WTC1. His mobility impairment was severe. He needed an air cast on his injured ankle, used crutches/stick and removed his shoe for improved comfort while working. He saw the aeroplane approaching. He knew it was a jumbo jet, felt the impact and knew it was serious. Participant C scored his perception of risk at this point as very high. He calmed his colleagues, told them to get out, and had to convince some to leave. Then he got a group of colleagues to search the floor for other colleagues and directed them to leave immediately, to quote *"they are looking for direction, they are not gonna to make those decisions on their own, so you have to basically step up and be an authority figure and say we are gonna do this, we are going here now and how we are gonna get done… we did it we got them all out"*. Participant C took nothing with him, i.e. he left his briefcase, stock certificates and shoe behind and did not stop to put on his air cast support or shoe. He evacuated the floor with a group of about 13 people which assembled at the entrance to the stairwell. Participant C noted that it took about 4–5 min to get everyone into the stairwell lobby and that when the stairwell door was opened there were already many people in the stairwell in which people were evacuating two abreast. The group of 13 exiting from floor 54 lined up and merged into the stairway flow in single file, i.e. they occupied half the width of the stair. The other half was occupied by upcoming fire fighters and people coming down from the floors above. They descended the stairs as a group, shuffling and waiting in turn to wind their way down floor by floor. They stopped many times and moved down half a flight at a time. It was very hot in the stairwell, people were discarding their clothes and some women were even discarding their panty hose. Participant C and his group had to wait many times for long periods as flows from other floors merged with the descending flow just as they had done when they entered the stairway at floor 54 *"the door would open and then people would come in and you'd let them go in front of you"*. The group also encountered fire fighters coming up—the fire fighters, together with injured people and a blind person were afforded free single passage past the group. The fire fighters were so thirsty they were taking soda from machines on floors on the way up. From floor 16 they passed people going down as they increased their pace.

On reaching the concourse, participant C was also directed to use the escalators to evacuate. According to participant C, he exited the building at 10.03 a.m.

As noted, participant C's mobility impairment was so severe that he could hardly walk. He used crutches/stick to get about his work place and removed his shoe for greater comfort. Yet, despite making allowances for some discrepancies in participant C's

estimated timings of events, his evacuating with only one shoe, his being forced to wait during the descent of the stairs to accommodate merging flows and upcoming fire fighters and overtaking by others, participant C evacuated unaided, felt no pain and literally ran away from the building on exiting—"*I walked and I ran and ran.*" Assuming that participant C took 5 min to get into the stair, his rate of descent on the stairs was approximately 1.3 floors/min.

4.4. Participant D

Participant D was located on the 17th Floor of WTC1. She suffered from severe sciatica, had a heart condition, was a diabetic and was recovering from having a hysterectomy. She was employed as a supervisor with the company. Following the impact, participant D thought that the building was going to collapse and scored her perception of risk as very high. She yelled at people to get out and forced open the office door which had jammed as a result of the impact on the building—"*my immediate thought was to leave and take the people that were there with me*". Participant D led her group of colleagues to the stairwell and estimated that they evacuated floor 17 in less than 5 min.

Participant D entered a practically empty stairway and descended in single file—"*force of habit, they tell you leave that side for people to come up—so that's what happened*" Further down the stairway was packed "*like sardines… with people and people were backing up. It was amazing, people just waited their turn*". The people in the stair moved aside to let injured people down and fire fighters up. At about floor 10 they got stopped; they could not go any further—the stair was congested. People in front were saying "*you have to go back—you have to go back*". There was a smell of smoke and fuel in the stairway. Participant D recalls "I know what jet fuel smells like, I live near an airport". Participant D's friend said "*you know we can't, we can't breathe this stuff, you gotta cover your mouth*", so he took off his shirt, tore it in half and gave her half to cover her mouth with. At this juncture they were in a group at the tail of the backed up queue in the stair, "*it had got to the point where we could not go any further*". Then somebody further down the stair shouted up "*we can't get out this way, we have to turn around and go back up stairs*". The group at the tail of the queue paused for a minute or two and decided to go back up the stairway; they exited onto floor 13 where they waited for some time before crossing over to a different stairwell. The decision to retreat back up the stair was taken by those at the rear of the group and entry onto floor 13 was by chance, i.e. a member of the group banged on the landing door until someone opened it. Coincidently, a similar incident occurred in the second stairwell entered, i.e. the group went down too far and had to back up a flight to exit the stair at the concourse level.

Participant D also noted using the escalators at concourse level and scenes of devastation and chaos. When participant D exited the building she ran until she "*could not run anymore*". This from a person who said about her descent on the stairs "*well I have sciatica—I thought I was moving fast but you know every pounding of the step is a pound in my back so you know. I think I was moving at a pretty good clip … if I had to go back up 10 flights I wouldn't have made it—but you know when your adrenaline gets going you get going… I had a hysterectomy so the pain and every once in a while I'm just reminded that I still have pain there, but the sciatica is what really slowed me down.*" She estimated her evacuation time to be 45 min, which suggests a stairwell descent rate of approximately 0.4 floors/min. It should be noted however that this estimated stairwell descent rate includes descending the stairs, waiting, retreating back up the stairs from floor level 10 to floor level 13, waiting on floor 13 for some time, transferring to another stairwell, passing the stairwell exit to the concourse and backing up a floor to exit the stairwell at the concourse level. In fact the estimated descent rate includes the free movement of the group led by participant D and, the restricted in part, movement of the group of which D was a member.

As noted earlier, participant D, although not involved in the 1993 WTC evacuation, was fire safety conscious and had informed herself of the location of the fire safety exits. It is clear that despite her physical and medical profiles, she overcame much to evacuate unaided.

4.5. Participant E

At the moment of impact participant E was on the 20th floor of WTC1, accompanied by two police officers who had helped her get into the building and get to her work station. The police officers ran off to find out what was happening and quickly returned telling participant E and others to get out of the building. Participant E decided to get out. At this juncture she scored her perception of risk as moderate, but noted that she was worried about falling, especially on the stairs—"*there's really a big guy like a linebacker and I said I just may need help with you will you go out with me, I may need crowd control if people start to panic, if people panic I may need you to restrain a crowd if they start to stampede*". She told others to get out and organised assistance from co-workers for herself, i.e. she was thinking ahead in terms of enlisting helpers to provide her with some measure of crowd control on the stairs. She evacuated the floor relatively quickly with her helpers, using her canes as walking aids, via the exit closest to her office. She actually organised three helpers telling them "*you know if you leave now, I will not fault you…I'm not going to put anyone in harm's way today so anything that we decide to do, we have to talk about it*".

Participant E and her three protectors/helpers (two males and one female) entered the stairway—"*we took up the whole stairway*" and joined the procession going down at a staccato pace "*you know hop-hop-hop-hop*". Her protectors formed a human cage around her, one male at the front and rear and the female at the side—"*she could cuddle up to me and let people by or if she needed to she could move out and control people coming alongside of us*"—while she held onto the handrail with her right hand—"*I held on for dear life*" and used her cane in her left hand. Ironically the group needed to stop on every other landing or so, not because of participant E's need but because two of her protectors suffered from asthma—"*both had asthma—we had to stop so we would go over to a corner on the landing–and huddle*". As they descended, the stairway became more crowded and their pace of descent slowed. Also participant E observed 6 or 8 people behind them, letting people pass them while they remained behind her—"*so people without talking to me had taken a responsibility behind me—not going by when they could—they understood implicitly their job as to slow up if needed—there was one guy who had the water—'here's the water hon you need it more than I do'—he could have said bye but he didn't he would move aside and go back to be kind of four people behind me*". Participant E was focussed on what she was doing and on reaching the Plaza level the door opened and they got out. Participant E reported that she and her protectors exited as a group by 9.15 a.m.

Participant E experienced great difficulty moving around the offices when not using her POV/scooter; in fact she used her secretary's wheeled chair to move herself around the offices. When walking short distances she used canes or sticks as mobility aids. Despite her physical and medical histories, participant E evacuated floor 20 of WTC1 by walking and using her cane as a mobility aid. She was very focussed on getting out of the building

and estimated that she exited the building at 9.15 a.m. Participant E did not specify the time delay before leaving the floor. Estimating from her account a time delay of 3–4 min would suggest a floor descent rate of about 0.8 floors/min. This seems remarkable as her descent was staccato, i.e. one step at a time and frequently interrupted. In effect, as it transpired, participant E's mobility impairment was not the only, or even the major, impediment to her safe evacuation. As it turned out her main impediment was the fact that two of her protectors/helpers suffered from asthma and had to frequently pause during their descent.

Participant E was very aware of her own vulnerability in an emergency. She had disaster management training, had evacuated WTC in 1993 and had made herself aware of where the fire exits were. She had made her children fire safety aware by pointing out them emergency fire exits in building they had visited and yet it would appear that a Personal Emergency Evacuation Plan (PEEP) had not yet been developed for her within her employing organisation. As it transpired on 9/11, she had PEEP in her head and organised her protectors/helpers immediately to ensure her safety during the evacuation.

4.6. Participant F

Participant F was on the 79th Floor of Tower 2, and saw the aeroplane flying in at eye level and hitting Tower 1. He knew immediately the seriousness of the situation, assumed his designated fire safety role and ran up and down between floors 79, 80, 81 and 82 three or four times telling people to get out—"*it was a no brainer—I worked for a Japanese bank and a lot of them did not leave because they felt they would be reprimanded for leaving… they get embarrassed very easily—a lot of people looked up to me*"—until he was told to get himself out and take the people on the 81st floor with him. At this stage he rated his perception of risk as 'very high'. He delayed long enough to collect some personal effects from his office and left with the others making their way to a stairwell before starting down. Participant F could not estimate the time he spent alerting and evacuating others before he evacuated from the 81st floor. However, it was clear that he was able to do all these activities with ease, despite a paralysed left leg.

When he entered the stairwell, participant F described the scene as "*like rush hour in the subway—it was crowded I appointed myself as the lead, the point man—I'm sure there were a lot of people who appointed themselves as lead*". They interrupted their descent and for some reason followed others onto floor 66 and waited, although it is not clear for how long. He estimated there were up to 100 people on floor 66. While on floor 66 they heard an announcement that it was safe to go back to their work stations. However participant F ignored this—"*I didn't pay any attention to it*"—assumed leadership of the group and the group recommenced their descent—"*people were going on to this particular stairwell so we had to wait, there was no pushing or shoving*". The stairwell was congested with other people coming down. Leaving floor 66 he met a woman who needed help—"*I was almost carrying a woman down the stairs—wasn't nobody getting by me and her cos we were like two pretty big people coming down those stairs*". Below floor 60 some fatigue among the evacuees was evident—"*it was impossible to rush because of fatigue, mental fatigue and physical fatigue—there were people sitting on the side and one guy covered in blood ran down the stairs with a towel on his head soaked—people just lumbering down lumbering down the stairs*". Remarkably participant F's paralysed leg, as he put it, "*did not bother me*". The group met fire fighters coming up at about floor 10 and moved aside to let them pass. As they went further down mental and physical fatigue slowed the pace of descent.

As participant F entered the lobby level—"*it was a war zone—a twilight zone—I came out of the stairwell and I didn't know where I was*". They were directed out of the building and used the escalators to transfer between levels. Despite participant F's first impression on entering the lobby level being that it was like being in a twilight zone and he did not know here he was, the final egress from the building was orderly with participant F holding open a final exit door for others for some time.

5. Group behaviour

It is well known that perception can drive behaviour [34]. Information, which is key, may be situational and/or personal, e.g. knowledge of one's own limitations, capabilities and fears may be framed contextually in the formation of an individual's role within a group. Thus for the 6 self-declared mobility-impaired participants in this study it is worth exploring their propensity to form groups in their evacuation of WTC. For the purposes of this paper, a group is defined as 2 or more people that interact with one another, accept expectations and share a common identity. Thus in this context, a group is more than a mere coalescence of individuals, without obligation to each other. Attention will focus on how groups formed, how they functioned and the social interactions that occurred in group formation and behaviour.

Participant E had detailed knowledge of her limitations and corresponding capabilities. She was afraid of falling over in as she put it "*a stampede on the stairs*". So she formed a group with three colleagues who surrounded her as a protective shield. They moved and rested as a group and changed shape as a group to facilitate overtaking by others and contra-flows. They were a small group in a restricted space, controlled by participant E; they had a common goal, few ground rules and a course of action dictated by events. As a group, given their concerns for each other, their actions and behaviour were predictable.

A collection of people also attached itself behind this primary group, without any apparent attempt or desire to overtake the primary group, thus apparently affording another layer of protection to the primary group. This might be described as affiliate group behaviour, with the primary group actually in control and is similar to the behaviour exhibited in [27].

Following the impact participant A joined up with some co-workers and at some point decided to get out of the building. But participant A left her colleagues and went back to her work station to collect some personal belongings. Then as she put it she "*followed the crowd*", exhibiting what might be described as herd behaviour, i.e. fleeing from imminent danger. From Table 2 it is evident that participant A knew the locations of the three stairwells, had evacuated WTC in1993 and was prepared for an evacuation by having a survival kit. So perhaps her following the crowd is not surprising if she knew the crowd were heading towards a stairwell. Although the pronoun 'we' is used frequently in the free flow narrative, suggesting there were others associated with participant A, there is no evidence that A was part of a coherent cohesive group. Participant A did encounter crowds but any semblance of collective behaviour is absent.

After the impact participant B teamed up with a colleague to shepherd people off their floor into the stairwells. They did this for some time as a group with a common purpose until participant B decided to part company with his colleague (who continued to search for others) and leave. He decided it was time to go—"*that was it for me, I had had enough, time to call it quits*". His basic survival instincts cut in and, coupled with his previous training, were sufficient for him to sever his links with the group he was in and leave. He met people in the stairwell he knew and he chatted to them as they made their descent but there is no evidence in the

free flow narrative of the formation of a group, apart from the primary group which he formed with a colleague and subsequently severed.

Immediately after the impact, participant C, together with other supervisors, rounded up people on their floor and got them to the stairwell. There were about 12 or 13 people in the group. They were a cohesive group with a common goal with participant C acting as an authority figure. At one point on their descent participant C dissuaded a colleague from going onto a floor to see what was going on "*you are coming down with me you have got two kids*" However, in the stairwell, participant C became semi-detached from the group finding himself several floors ahead of them. In fact he moved down quite fast, passing people on the way down—"*I definitely passed people from floor 16 down, there was no point, there was no reason for me not to go as fast as I could. I wasn't an emergency worker, I wasn't a fire… I wasn't anybody, I shouldn't just move slowly for fellowship, you know what I mean? I should go as fast as I can, I mean that's what I had no question about it*". So participant C got his group into the relative safety of the stairwell, dissuaded a colleague who had two children from going out of the stairwell onto a floor to have a look around, but beyond that saw no point in delaying his descent as he put it "*for fellowship*". He left the group to descend at their pace while he descended at his much faster pace. Although he gathered the group together and got them to relative safety in the stairwell, he was not dependent on the group or anyone else but himself for his survival. His bond with the group, which he formed, was such that he could detach himself from the group and group obligations to make his escape from the building.

Participant D, after the impact, told colleagues to get out of the building and they left together. At the stairwell the group broke up and participant D was left with a colleague—"*the two of us stuck together*". Her colleague was in shock—"*what are we going to do?*"—to which D's response was "*we are gonna go—and that's what we did*". Part way down the stair, jet fuel fumes were present, and participant D's colleague tore up his shirt giving her half to cover her mouth and nose with. So here we have an initial group which formed to get off the floor which then breaks up at the stairwell leaving a primary group of two exhibiting different behavioural characteristics, i.e. authoritative, knowledgeable and protective. As the two descended they became part of a queue of people on the stair until they could proceed no further and were advised to go back by someone at the head of the queue. Someone at the tail of the queue turned and went back up and they followed, eventually making their way out of the building.

Participant F in Tower 2, after traversing several floors getting people to leave, was instructed to leave and to take people with him; this he did and led his group to the stairwell. Participant F took the lead; the group had a common goal and they joined the descent flow. They got down to floor 66 and participant F followed those in front onto the floor and his group followed him where they waited for a while until participant F decided "*we're outta here*" and they restarted their descent. At around floor 62/63 he met a woman who needed help and he "*almost carried her down*"; as it turned out the support to each other was mutual but different, i.e. his physical, hers motivational. Again we experience the gathering of a group which participant F led to the relative safety of the stairwell, followed by herd behaviour as the leader of the group followed by his group follows a crowd onto floor 66. Later, through an encounter with a woman needing help, another group is formed. In this case, as in others, the transient nature of groups is apparent.

6. Discussion

Of the 271 participants in the HEED study, only 6 declared mobility impairments on their pre-interview questionnaires. Their mobility impairments ranged from severe "*could not walk to work*" to not severe "*not obvious—walked to work*" and from permanent to temporary. The nature and type of mobility impairment also varied and was usually accompanied by one or more medical conditions which could have some bearing on the individual's mobility capability. Other non-obvious potential mobility impairments such as asthma were not always declared.

Notwithstanding the physical and medical profiles of the participants, all overcame their mobility impairments to safely evacuate the WTC towers. Although their behaviour and experiences varied somewhat over time, they all experienced merging flows, contra-flows in the stairwells, deference behaviour and variable descent rates in the stairwells. The participants in the floors closest to the impact zone, i.e. participants A–C, each managed estimated descent rates in the stairwells of 1.3–1.4 floors/min. Participant D, who had a heart condition, diabetes, hypertension, sciatica and was recovering from a hysterectomy, managed a stairwell descent rate from the 17th floor of approximately 0.4 floors/min, whilst participant E, evacuating from the 20th floor with her group of three helpers/protectors, managed to achieve a stairwell descent rate of 0.8 floors/min.

Comparison of these descent speeds with those estimated in the NIST study [29] indicates, perhaps surprisingly, that three of the 5 participants for whom descent speeds could be estimated, i.e. participants A–C, had speeds equal to the mean and greater than the median normalised travel speed reported by NIST (1.3 and 1.2 floors/min, respectively). Participants D and E on the other hand had speeds which were in the lower quartile, i.e. <0.9 floors/min. It is important to note, however, that in both studies the speeds reported are normalised travel speeds, i.e. the time from entering the stairwell until leaving the building divided by the numbers of floors that had to be descended, i.e. they are not necessarily continuous movement speeds and, in some cases, include time spent waiting on intermediate floors, reversing direction and escalator travel times on the concourse level.

These results are perhaps surprising, given the physical and medical profiles of the self-declared mobility-impaired participants. The question therefore arises as to how, in developing a fire safety engineering design of, e.g. a public assembly type building, the evacuation capabilities of individuals, relative to their declared mobility or other impairments, could have been determined? In all probability, due to a dearth of useable data, engineering judgement is used to fill the void. Engineers are, for example, expected to use pedestrian flow data which the original researchers have suggested be withdrawn from publication [35] and data sets in relation to people with disabilities [23] which are relatively sparse.

There is currently no phenomenology of mobility-impaired evacuation capability, and the work necessary to address this real, present and rapidly increasing need is not being done. For example, an international technical document, in its most recent edition [36], stated that occupant behavioural scenarios involved a description of the mobility capabilities of the occupants of buildings, but there is no meaningful attempt to actually describe the mobility capabilities of the mobility-impaired occupants of buildings.

Although the descent rates of those with mobility impairment on the stairs in this study were relatively high, the descent was often not continuous or constant. In some cases the descent was staccato, i.e. one tread at a time. Also the descent of some of the participants was perturbed by groups of fire fighters climbing up the stairs, i.e. the descent paused, and necking in the stair width occurred, as evacuees squeezed together to facilitate contra-flows and overtaking.

The evacuation of participant E, in particular, illustrates the need for escape routes of widths sufficient for assisted evacuation

without perturbing, impeding or stilting the evacuation of others. Participant E and her three assistors huddled together on every other landing in order to accommodate overtaking and contra-flows on the stair. Participant E's group also paused quite frequently to allow two of the assistors to recover from their exertions as they suffered from asthma. In Ref. [26] the sufficiency of escape route widths to accommodate 5 types of assisted evacuation was investigated and recommendations made; a stair width of 1200 mm was suggested as a minimum to accommodate assisted evacuation from upper floors during an uncontrolled evacuation. The width of the stair used by participant E was 1100 mm. The results of this study give cause to reflect once again on whether the provision of means of emergency egress for all occupants of buildings is adequate and sufficient for the purpose.

In this evacuation, the physical and medical conditions of each participant, together with their associated pains and anxieties, seemed to be set aside when their survival became paramount. This induced survival behaviour may be explained by the participants' awareness of imminent danger, perceived level of personal risk (which varied in the range moderate to high depending on what floor they were on and what cues they were first exposed to), and instinctive flight behaviour. In Ref. [37] a conceptual relationship between motion and emotional state was introduced with the transition in emotional state being represented by three phases. Phase 1 relates to the detection of signals of potential danger with associated adjustments of the individuals' psychophysiological systems. The second phase is characterised by increased activity associated with behaviour directed at the elimination of the danger. As the threat becomes more obvious activity increases to mitigate the threat; movement increases in all dynamic attributes (velocity, acceleration and effort); there may be increased efficiency in processing information and decision-making heuristics. Avoidance expectations related to increasing feelings of powerlessness characterise the third phase. Clearly the participants in this study were in the second phase, and it seems that, in most cases presented, the level of emotional response relative to the increasing life threatening danger induced psychophysiological responses sufficient to overcome physical impairments and associated pain. Interestingly this was not the case for the asthmatics providing assistance to participant E, i.e. they had to rest frequently in order to recover sufficiently to proceed.

It would appear, however, that even in chaotic situations human beings seek to impose and prefer order. For the most part the evacuation was conducted in an orderly fashion, despite the participants' high levels of risk perception. Although highly motivated by self-preservation instincts, social norms prevailed, i.e. no pushing or shoving but rather politeness and, in many cases, deference to others.

It is often overlooked in the provision of fire safety in buildings, particularly in multi-tenant occupancies, that the ethos of the organisation occupying the building or part and the cultural identities of the occupants can have a profound effect on evacuation inertia in the event of an emergency. Participant F makes it very clear that organisational ethos and cultural identity can negatively impact on building evacuation.

Another factor that played a part in participants' behaviour and actions was their level of fire safety awareness and evacuation experience. Three of the participants in this study had evacuated WTC in 1993 and the three who had not had some real fire evacuation experience and, in one case, fire safety-related responsibilities. As such, all exhibited some level of evacuation preparedness which ranged from carrying a safety backpack to establishing, to their satisfaction, the location of entrances to the stairwells. This level of preparedness, together with their knowledge of the developing situation around them, begins to explain their flight behaviour and their relatively rapid floor evacuation times. It has been shown in this study and in other studies of WTC 9/11 [29] and evacuation of other buildings [38], that evacuation preparedness through experience and fire safety training can overcome evacuation inertia.

Notwithstanding, a major area of concern is with regard to the nature of the fire safety training given to employees in some of the tenant companies occupying the WTC towers. None of the six participants with mobility impairments knew where the evacuation stairs actually discharged into. This might explain why, more than once, participants progressed down the stairs past their actual discharge floor. Some also had to familiarise themselves with the actual entrances into the stairwells because during drills the stair lobbies were crowded and they could not see.

A group as defined for the purposes of this paper is significantly different from a mere assemblage of people which has no common identity. It is clear from the information distilled from the mobility-impaired participants in this study that groups may be formed for a variety of reasons, e.g. personal need. An individual's role as a supervisor or floor safety warden, for example, may result in the gathering of people to form a group of evacuees. However, just as groups form and individuals are bonded into the group, groups may also fragment in that individuals may, for a variety of reasons, detach themselves from the group and smaller groups may be formed. In this paper two types of group associated with the participants are distinguished, i.e. primary and affiliate groups. A primary group may be formed by an individual with knowledge of their limitations, capabilities and fears and sufficiently resourceful to recruit others to their aid, e.g. participant E. Primary groups may be characterised by being expectative, interactive, supportive, assertive, defensive, protective and assistive in pursuit of a common goal. There is evidence also that others, not members of the primary group, may affiliate with the primary group and proceed in tandem with it, taking its lead from the primary group without actually being part of the primary group. Although there is evidence of herd behaviour, i.e. following the crowd, it is clear that the crowd followers had knowledge of the locations of the stairwells and may have followed the crowd because it was moving towards a stairwell. There is no evidence of a dependency on the followers of the crowd for their survival as they had exhibited their preparedness for evacuation previously.

7. Conclusions

Despite their physical and medical profiles, all of the mobility-impaired participants in this study achieved remarkable stair descent rates and total evacuation times.

The relationships between emergency information processing, decision making, movement and emotional state need to be researched and better understood, particularly the emotional state that overrides mobility impairments, medical conditions and associated pain.

The term "mobility impaired", routinely assigned to individuals with various physical conditions, is an inadequate and insufficient descriptor of their actual evacuation capabilities in fire. The body of work currently available from which one can determine realistic life safety capabilities of people with mobility impairments and other disabilities is inadequate and insufficient for the purposes of performance-based fire safety design. Measures compatible with an individual's life safety capabilities in a fire emergency need to be determined, and data sets related to agreed levels of mobility impairment, produced as a matter of urgency.

The sufficiency of escape route widths to accommodate overtaking of slower individuals has once again been questioned

in this study. The width of escape routes in buildings should be sufficient to provide for the safe evacuation of mixed ability populations, including assisted evacuation of occupants, overtaking and contra-flows.

Knowledge of one's limitations, capabilities and fears in any given situation necessitating immediate evacuation, coupled with an innate ability to use such knowledge to best advantage, may be a catalyst for primary group formation. Two types of groups have been distinguished in this paper, i.e. primary and affiliate groups, and there is evidence of group fragmentation. The formation and operation of primary and affiliate groups is an important area for future study.

Participants with previous real fire evacuation experience implemented practical self-preservation evacuation strategies and acted authoritatively, particularly where they had specific safety duties and line management responsibilities. However, the testimony of the participants in this research raises serious questions in relation to the nature, content, delivery and effectiveness of fire safety training programmes and associated fire drills. More attention also needs to be given to the potential impact of an organisation's ethos and employees' cultural identity in the development of fire safety engineering designs and fire safety staff training programmes.

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