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The UK 9/11 evacuation study: Analysis of survivors' recognition and response phase in WTC1

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ABSTRACT

The September 11th 2001 impact on the World Trade Centre (WTC) resulted in one of the most significant evacuations of a high-rise building in modern times. The UK High-rise Evacuation Evaluation Database (HEED) study aimed to capture and collate the experiences and behaviours of WTC evacuees in a database, which would facilitate and encourage future research, which in turn would influence the design construction and use of safer built environments. A data elicitation tool designed for the purpose comprised a pre-interview questionnaire followed by a one-to-one interview protocol consisting of free-flow narratives and semi-structured interviews of WTC evacuees. This paper, which is one in a series dealing with issues relating to the successful evacuations of towers 1 and 2, focuses on cue recognition and response patterns within WTC1. Results are presented by vertical floor clusters and include information regarding cues experienced, activities prior and subsequent to occupants first becoming aware that something was wrong, perceived personal risk, time taken to respond and the inter-relationships between them. The results indicate differences in occupant activities across the floor clusters and suggest that these differences can be explained in terms of the perception of risk and the nature and extent of cues received by the participants.

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1. Introduction

The terrorist attack on the World Trade Centre (WTC) in New York 2001 resulted in one of the largest full-scale evacuations of high-rise buildings in modern times. Several studies have already investigated the evacuation of the WTC using published accounts from survivors, questionnaires, interviews and focus groups and the results have been published [1–3]. The UK project High-rise Evacuation Evaluation Database (HEED) [4,5] was funded by the Engineering and Physical Science Research Council (EPSRC), UK, and conducted by the Universities of Greenwich, Ulster and Liverpool. The main aim of the HEED project was to capture and present detailed and multifaceted behaviours and experiences of the evacuees of towers 1 and 2 in a relational database, which would facilitate research towards the design, construction and use of safer built environments.

The HEED project aimed to develop a better understanding of the inter-relationships between a developing fire, human behaviour and building technology. This was achieved by the 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 evacuation behaviours.

It has long been recognised that a primary factor contributing to deaths from fire is delay in warning occupants and extended times before movement commences. Work by Proulx and Sime [6] and Sime [7] suggests that the delay in starting positive evacuation actions can be much longer than the time to travel the distances to and through exits. During this time occupants may be inactive, but may also be involved in a range of behaviours involving movement such as searching for information, alerting others, etc. These pre-evacuation activities have been documented in a number of papers and reports [8–10] and many studies have been designed to investigate the duration of this delay time in a range of different building types [11–16].

Over the years, different terminologies have been used to describe this delayed time to start. The terminology used in current design guidance such as PD7974-6 [17], for example, is 'pre-movement time', which is defined as "*the interval between the time at which a warning of a fire is given and the time at which the first move is made towards an exit*". However, other terminologies used include 'response time', 'delay time' and 'pre-evacuation activity time' (PEAT).

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Although PD7974-6 [17] and other guidance documents have, through necessity, attempted to consider this part of the evacuation in a rather simplistic manner (PD7974-6 suggests it is a function of the alarm, building complexity and management), it has become clear from the studies that have been conducted that our understanding of human behaviour during this phase is insufficient and should be considered in relation to different contextual settings [18,19].

The HEED database, developed as an output of the UK WTC project, is structured to include behaviours and experiences during seven distinct phases that evacuees encountered during 9/11, namely: pre-recognition, recognition, response, horizontal evacuation, vertical evacuation, evacuation interruption and exiting the WTC complex.

This paper, which is one in a series of papers dealing with issues relating to the successful evacuations of towers 1 and 2, focuses on the extraction and analysis of data in the HEED database in relation to the *recognition and response* phases in WTC1. An analysis of the recognition and response phase in WTC2 is expected to be different from that in WTC1 due to differences in initial cues (which for WTC2 include impact on WTC1), and will be the subject of a later paper.

For the purposes of this paper, recognition and response phases together are defined as 'the time from when an occupant receives the first cue until they start to move towards an exit'. The paper presents an analysis of the cues received by evacuees, their subsequent activities and time taken to respond. As noted earlier the HEED study set out to determine individuals' risk perception at various points during their evacuation. Studying an individual's perception of risk helps us understand the subjective nature of a person's attitudes towards the danger of a hazard [20]. However, although some studies have started to develop models of risk perception based on the events of WTC 9/11 [1,2], this is an area that has been under-explored in relation to fire. Both Galea and Blake [1] and the NIST study [2] suggest that the perception of risk is related to the quality of information gained, while NIST found additionally that environmental cues and floors had strong relationships with perceived risk in both WTC1 and WTC2. This paper will therefore also explore occupants' perceived risk and the relationship between perception of risk and subsequent evacuation behaviour. The analysis will also consider the impact of location (in terms of floors) on behaviour. It is not unreasonable to assume that different cues might be experienced, and different behaviours might result, depending on participants' location in the building, i.e. nearer to or further away from the impact zone. NIST [2], which sub-divided occupant location into three zones according to the location of the mechanical floors, i.e. floors 1–42, 43–76 and 77–91, found significant differences in the delay time to evacuation in WTC1 among the three zones. For this reason, differences in cues received and activities conducted in the response phase for different zones within the building will also be explored in this paper.

2. HEED study methods

A detailed account of HEED study methodologies has been presented by Galea et al. [4]. In brief it comprised a:

- *Pre-interview questionnaire*—this was designed to extract basic factual information from the participant, including information related to the participant's sex, age, pre-existing medical health, knowledge of the layout of the WTC, whether they had a fire safety role, fire safety training received and so on. The pre-interview questionnaires were then used to inform the subsequent elements of the data retrieval process.
- *Free-flow narrative*—the interview was constructed around the participants recollecting and telling their evacuation stories in their own words and in their own time. Each participant was encouraged and assisted to recall the morning of 9/11 by way of ordinary everyday events, e.g. preparing to leave home to go to work/getting to work and then to describe their experiences from the time they entered the WTC towers until they finally exited the towers. This narrative format was used to enable the participants to relax and recall the events experienced in WTC on 9/11 and reveal behaviours and experiences in rapidly deteriorating situations that they might not have considered relevant or important.
- *Semi-structured interview*—this section permitted the interviewer to clarify details and elicit more precise information regarding the participant's entire evacuation experience, over time and location.

The methodologies outlined above, when viewed and used separately, yielded a substantial amount of data and related information. However, when integrated, the yield of quality data and information was increased by several orders of magnitude, a distinguishing feature of the data and information retrieval systems used in this research.

2.1. Time classification

An important aspect of the HEED investigation that is particularly relevant to this paper is that, throughout, interviewers attempted to extract information from the participant in relation to the time and location of their described experiences, i.e. the response times are an estimate by the researchers based on information provided to them by the interviewees. Where the absolute time that an incident occurred could not be determined, the interviewers attempted to determine the times relative to global time markers. This process involved defining a total of 19 time sub-intervals around the four known global event times, namely the impact on WTC1 at 8:47am (T1), the impact on WTC2 at 9:03am (T2), the collapse of WTC2 at 9:59am (T3) and the collapse of WTC1 at 10:28am (T4). The sub-intervals relevant to the recognition and response phase are:

- closer to T1 than T2 (between 08:47 and 08:55, 8 min duration),
- between T1 and T2 (between 08:47 and 09:03, 16 min duration),
- closer to T2 than T1 (between 08:55 and 09:03, 8 min duration),
- shortly before T2 (between 09:02 and 09:03, 1 min duration) and
- shortly after T2 (between 09:03 and 09:13, 10 min duration)

2.2. Perception of risk

A retrospective questionnaire was designed to determine participants' perception of risk at four 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 WTC2 had collapsed (if applicable). The risk perception questionnaire comprised a general question on how at risk they felt at the time in addition to a subset of more detailed risk perception questions. The responses to the general risk perception question, which was

used in this paper as a general indicator of the participants perception of risk over time, was rated on a seven-point Likert scale from 1 ('no risk') to 7 ('very high risk'). More detailed information on the participants' perception of risk using the more incisive risk perception questions will be included in subsequent papers.

2.3. HEED

HEED, which was developed using Microsoft (MS) Access, is a flexible interactive research tool designed specifically to systematically store and facilitate analysis of data and information distilled from the transcribed interview accounts from the HEED WTC evacuation study. The information stored in the HEED provides a means to address key research questions relating to human factors issues associated with evacuation from high-rise buildings and other complex built environments. A detailed description of the development of the HEED in parallel with the development of a coding framework for the transcribed interviews is given in Galea et al. [4]. Data within HEED are stored using the logical arrangement of a three-level Experience hierarchy. The highest level of the hierarchy is the Experience Category or Level 1 experience. There are six core experience categories, namely: Action, Sensory, State, Cognition, Dialogue and Risk Perception. Below the Experience Category is the Experience Type or Level 2 experiences, which identify the nature of the experience. The final element in the hierarchy is the actual Experience extracted from the text, also referred to as the Level 3 Experience. For example the experience of feeling the building shake would be coded: Level 1 Experience Category—Sensory, Level 2 Experience Type—Environmental Condition, Level 3 Experience—Building Shake. In addition to coded Experience information, the HEED also includes supporting contextual information such as the time of the experience and the participant's location, as well as full transcripts for each interviewed participant and the pre-interview questionnaire responses.

The data collection for the HEED project has been comprehensive, resulting in a large quantity of rich data and quality information for future analysis. Consequently the coding framework and immediate HEED development priorities have focused on issues considered to be of particular relevance to fire safety engineering, e.g. cue recognition and response; group formation; choosing and locating an exit route; conditions hindering egress; merging flows and deference behaviours; and fatigue and travel speeds. HEED therefore encapsulates all of the participants' perceived evacuation experiences such as stimuli (e.g. observational cues), cognitions (e.g. incident interpretations) and individual and group behaviours (e.g. actions and reactions). It also contains information that develops, expands and contextualises the identified experiences by including the where and when, why the experiences occurred and with whom the experiences may have been shared.

3. The sample

Details of the HEED recruitment process are given in Galea et al. [4,5]. HEED comprises the transcripts and coded data from 271 persons who evacuated the WTC towers on 9/11. As this paper's focus is on the recognition and response phase for WTC1 evacuees only, the data presented relates to a sample of 126 persons who evacuated the WTC1 on 9/11.

This sample comprised 62.7% (n=79) male and 37.3% (n=47) female; ages ranged from 24 to 68 (mean age of 46.3). The majority of the sample (65.1%, n=82) indicated that their highest level of education was university; 5.6% (n=7) high school; 29.4% (n=37) of the participants did not disclose such details.

Pre-interview questionnaires examined the duration of the participants' employment in the WTC1 at the time of 9/11 to gauge the potential familiarity of the participant with the building. A total of 84.1% (n=106) participants answered this question. Of these, just under a quarter indicated that they had worked in the WTC1 for 2–5 years (23.8%, n=30), 14.3% (n=18) for 7–12 months and 10.3% (n=13) for less than 6 months. In addition, analysis of the pre-interview questionnaire indicated that 19% (n=24) participants evacuated the WTC during the 1993 bombing.

A designated fire safety role was assigned to 8.7% (n=11) of WTC1 participants within their respective organisations. These roles included Floor Warden (4%, n=5), Deputy Floor Warden (3.2%, n=4) and Searcher (1.6%, n=2), which were held between 4 months to over 20 years. For those participants who had a designated fire safety role, 81.8% (n=9) had received specific training from their employers. Further breakdown of the duration of holding a fire safety role revealed that for the 10 out of 11 who answered this question, 20% held a designated fire safety role for under 1 year (n=2), 30% (n=3) between 1 and 2 years, 20% (n=2) between 3 and 4 years and 30% (n=3) for over 5 years.

The sample of WTC1 evacuees in this study is similar to the estimates of the population of WTC1 made by NIST [2], i.e. for this sample and NIST estimates respectively: mean age 46 and 45; gender—63% and 65% male. In addition the evacuation experiences (in terms of involvement in 1993 evacuation of WTC1) were similar, i.e. 16% and 19%, respectively.

4. Procedures for analysis

As noted previously, HEED captures all participants' evacuation experiences such as stimuli (e.g. observational cues), cognitions (e.g. incident interpretations) and individual and group behaviours (e.g. actions and reactions) within the three-level Experience hierarchy. It includes behavioural patterns (BPs), i.e. chunks of transcript text that contain experiences and corresponding contextual data. Supporting information such as the time of an experience and participant's location are also captured by associated contextual information. The information available in HEED was utilised for this analysis relating to the recognition and response phase in WTC1. To permit the analyses, it was necessary to download and merge the pre-interview questionnaire data, coded experience data, including risk perception measures, each participant's BPs and, in some cases, direct information from the transcripts. This was coded into Statistical Package for the Social Science (SPSS) [21]. To determine each participant's activity sequence during the response phase, the chunks of text from the BPs relative to that phase were coded into SPSS as categories of activities. The participant's activities and associated cues were coded in a sequential form. Coding was initially completed in terms of participants' own descriptions of their activities rather than forcing them into predetermined categories. A total of 69 raw activities were identified, which, for practical purposes, were combined and reduced to form 17 activities deemed appropriate for detailed analysis. The raw activities were reduced by considering naturally occurring themes of activities, which were independently identified and agreed within the research team. As part of this process, response activity definitions were developed to uniquely describe the consolidated grouped activities. Cues received were treated in a similar manner. The definitions of cues received and response activity used in this study are given in Tables 1 and 2, respectively.

Table 1
Cue definitions in the recognition phase.

Heard impact	Environmental sounds as heard by the participant inside and outside the WTC, e.g. explosion and crunching sound
Felt impact	Physical sensation, e.g. felt building shake and physically moved by impact, experienced by participant
Saw or heard incoming plane	Saw or heard an aeroplane that was heading towards their tower, e.g. saw incoming plane, plane becoming higher pitched, heard roaring sound
Saw smoke/fire internally	Saw smoke or fire inside the tower, e.g. elevator on fire and saw smoke
Saw smoke/fire externally	Saw smoke or fire outside the tower, e.g. saw burning debris outside WTC, saw burning liquid falling
Experienced internal phenomena	Heard, saw, smelt and/or felt surrounding environmental conditions inside the tower, e.g. heard screaming, metal in tower groaning and lights flickering
Saw external debris	Saw environmental conditions outside the tower, e.g. saw plane debris and saw debris falling

Table 2
Response activity definitions.

Act of normal routine prior to evacuation	Participant conducted act(s) of normal routine, which include locked office door, switched off electrical appliances, used toilets, locked away item
Active protective action (self and others)	Activities such as: took cover (hid behind, under or inside something in order to remove himself/herself from harm's way), distributed emergency item, combated fire, blocked or sealed smoke cracks
Collected belongings	Participant collected an item that was originally used for personal or work purposes, e.g. handbag, cell phone, laptop, discs and clothing
Continued to work	Participant sustained normal working behaviours, e.g. finished work, text message, phone call, trading
Gathered and/or made emergency equipment	Participant gathered and or made item(s) that may be deemed necessary in the evacuation, e.g. fire extinguisher, flashlight, whistle, emergency hammer, water, cloth to act as a mask for a smoke barrier, etc.
Grouped together	Participant assembled with other(s)
Physically removed people from situation	Participant physically removed other(s) from either a situation or an activity deemed dangerous by the participant, e.g. physically removing others who insisted in continuing to work
Provided assistance verbally	Participant assisted others by, e.g. verbally providing direction to evacuate
Provided information to emergency services	Participant used a telephone in an attempt to provide the emergency services with information, which may include whereabouts of the participant and the events occurring in the building
Provided information to external source	Participant used a telephone to provide external sources (e.g. family and friends) with information
Provided safety instructions	Participant instructed other(s) to hide behind, under or inside something in order to remove themselves from harm's way
Provided verbal instruction to evacuate	Participant suggested to or instructed others to vacate the building
Searched (physically and verbally)	Participant either actively searched or verbally called out in search for other/s. Searches included open plan and/or enclosed areas, e.g. offices and bathrooms
Sought information on event	Participant gathered information from other(s), dialogue or observation, e.g. physically moving to seek information or making phone call to security
Waited for further information/ instruction	Participant waited, e.g. on announcement of safety procedures, rescue and finding out more information

5. Results obtained

As stated previously, the main aim of this paper is to present the participants' behaviours and experiences in terms of their cue recognition and behaviours prior to the actual commencement of their evacuation of WTC. The results presented in this paper include information in relation to location in WTC1, cues experienced, activity prior and subsequent to first becoming aware that something was wrong, perceived personal risk, the time taken to respond to unfolding events and the relationships between these and other factors.

5.1. Location of participants

The locations of participants in WTC1 are represented in Fig. 1. From Fig. 1 it can be seen that participants were fairly well distributed across all floors from the 1st to the 90th floor. Floors 70–75 (n=18, 14.5%) contained the largest grouping of participants followed by floors 25–30 (n=15, 12.1%). The bottom 10 floors were less represented in the sample, encompassing only 2 (1.6%) participants. For the purposes of this paper, and further analysis, three floor clusters (identical to those adopted in the NIST study [2]) have been defined. These clusters comprised floors 1–42, 43–76 and 77–110, which were the locations of 45 (36.4%), 57 (46.0%) and 22 (17.7%) participants, respectively. On 9/11 the plane impacted the north face of WT1 floors 93–99, i.e. those in the upper cluster were closest to the impact zone.

From the semi-structured interviews, it was also possible to establish, for the majority of participants (80.6%), their location on floors, i.e. (north, east, south or west; Fig. 2). It can be seen that participants were fairly evenly distributed, with the majority of participants located on the impact side of the WTC1 (north side) and the south west corner.

5.2. Pre-impact position and activity

The majority of participants in the three floor clusters indicated that they were located at or around their work stations at the time of impact (n=78, 61.9%), with the remainder being in various other locations including others' work stations/office, lobby, elevator, etc. The pre-impact activity of participants is given in Fig. 3. Not surprisingly, given the above, the most frequent pre-event activity was 'working on computers' (n=43, 34.1%) followed by 'talking' (n=36, 28.6%). Of the participants who indicated that they were talking, 47.2% (n=17) were located at their work station, while others reported that they were talking 'at others work stations/office' (n=7, 19.4%) and 'on the floor where their own office was located' (n=7, 19.4%).

5.3. Initial cues related to impact (recognition)

During the interview, participants were requested to describe how they first became aware that something was wrong. Table 3 presents a breakdown of the participants' initial cues by floor cluster.

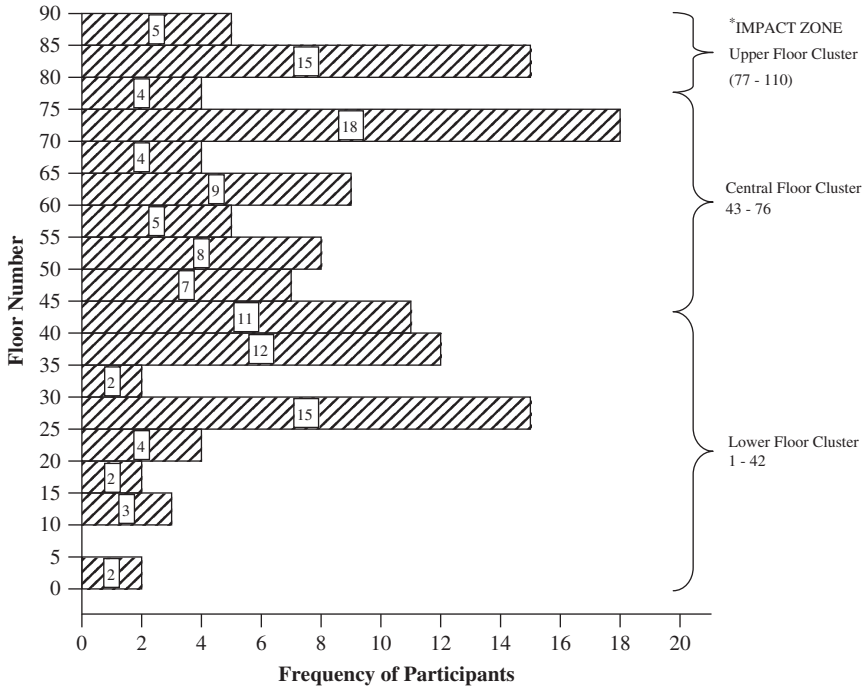

Fig. 1. Floor distribution of participants in WTC1.

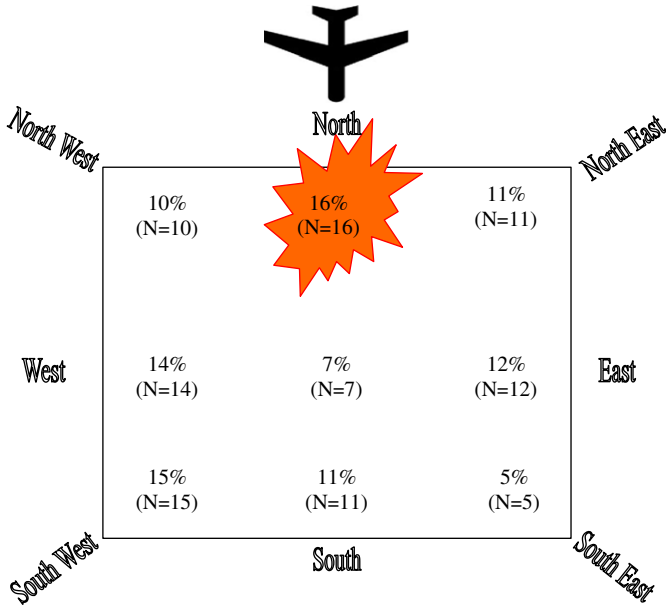

Fig. 2. Participants' location in WTC1.

In total, over 10% saw and/or heard the plane that impacted WTC1. Of these, 71.4% (n=10) were located on the impact side of WTC1 i.e. north (North, North West and North East in Fig. 2) while the remainder were located in the Eastern (14.3%, n=2), South Eastern (7.1%, n=1) and the central locations of WTC1 (7.1%, n=1).

Overall, close to 97% of participants across all floor clusters indicated that they felt the impact. In addition, approximately 65% of all participants indicated that they heard an impact sound and perhaps not surprisingly, this was experienced by a greater percentage of participants (83.3%) in the upper floor cluster than those in the lower and central cluster. Furthermore, from Table 3, it is evident that participants from the upper floor cluster were proportionately more likely to experience 'internal phenomena' than those participants in the lower and central floor cluster; however, the differences between floors were small (44.4%, 42.1% and 54.2%, respectively, for the lower, central and upper floor clusters).

Fisher's test was used to identify statistically significant proportional differences between the floor clusters in relation to the initial cues experienced by the participants. It was found that significantly more participants in the upper floor cluster in comparison with those located in the central floor cluster experienced 'seeing fire and smoke internally' (p=0.01). In addition, the proportion of participants in the upper floor cluster who 'heard impact' was significantly higher than the proportion of participants in the central floor cluster (p=0.02) and trend differences were found between the upper and lower floor clusters (p=0.08).

Notwithstanding some differences outlined above, it is evident that that many of the same type of cues were experienced across the floor clusters. However, although impossible to quantify, there were also differences in the intensity of the cues experienced across floor clusters. The impact of these cues are best described in the interviewees' own words. For example, the words of a participant located in a hallway on the 90th floor close to the impact zone provides an insight into the variety and intensity of initial cues experienced in the upper floor cluster:

> "*Leaning against the wall, drinking my coffee and reading The Times, when all of a sudden everything occurred and I remember there were 2 sounds: the first was a sound of a very big metallic banging sound…then followed by a deep rumbling sound when everything just sort of exploded. The wall in front of me, bubbling kind of flames came roaring towards me. The ladies room door opened against the hinges, just sort of snapped open against the hinges and out came a plume of burning… of flame…*"

In contrast, a participant located on the 13th floor, i.e. in the lower cluster, indicates that he/she also heard, felt, and experi-

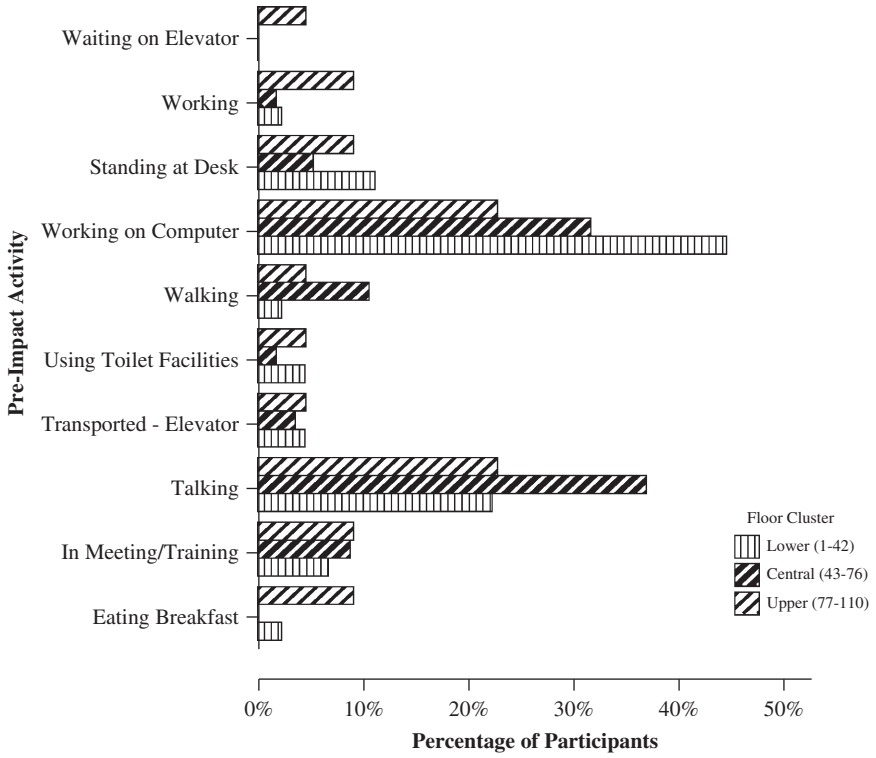

Fig. 3. Participants' pre-impact activity in WTC1.

Table 3
Initial cues indicating something was wrong.

Initial cues	Floor cluster			
	Lower (1–42) % (n=45)	Central (43–76) % (n=57)	Upper (77–110) % (n=24)	All floors % (n=126)
Felt impact	97.8	98.2	91.7	96.8
Heard impact	64.4	57.9	83.3	65.1
Experienced internal phenomena	44.4	42.1	54.2	45.2
Saw external debris	15.6	17.5	12.5	15.9
Saw or heard incoming plane	8.9	12.3	12.5	11.1
Saw smoke/fire internally	0.0	7.0	29.2	8.7
Saw smoke/fire externally	4.4	1.8	0.0	2.4

Note: Calculations for Table 2 are related to percentage of participants on each floor cluster.

enced internal phenomena but the overall experience and interpretation was different:

> "*It was of course fairly loud and the obvious reaction was 'what the hell was that?!' At that point the building moved from north to south …. I thought the building was going to topple over…. But the building did snap back into position right away and then the ceiling tiles started to fall….. and one landed directly to my right on the desk…. and I started seeing debris fall into the courtyard between Towers 1 and 2… out of the corner of my left eye. So at that point it was pretty clear that something was amiss… you know the noise was just very sudden and at that point it could have been …… a steam explosion or something*".

5.4. Initial response activities

Table 4 shows the participants' initial activity during their recognition and response phase in WTC1. The most frequently occurring initial response in all floor clusters was to 'seek information on event' (24.6%). The second most frequent initial response was to 'collect belongings' (17.5%), followed closely by 'provided verbal instruction to evacuate' (15.1%). It was also observed that over 10% of participants 'initiated evacuation' as a first response.

From Table 4 it is apparent that there are some differences in the initial response of participants across floor clusters. For example, participants in the upper floor cluster were more likely to take 'active protective action' (16.7%) as a first response compared with other clusters. They were also more likely to 'provide information to external sources' (8.3%) and 'provide information to emergency services' (4.2%). It is also interesting to note that none in the upper cluster reported 'waiting for further information/instruction' or indeed 'continuing to work' as a first action.

Participants in the central floor cluster were more likely to 'collect belongings' (24.6%) than those in the lower cluster (8.9%) and upper clusters (16.7%). The differences between the central and lower floor clusters were significant (Fisher's p=0.03); the reason for the greater prevalence of this activity in the central cluster is not clear.

Table 4
Initial response activities to the impact on WTC1.

Initial activities	Floor cluster			
	Lower (1–42) % (n=45)	Central (43–76) % (n=57)	Upper (77–110) % (n=24)	All floors % (n=126)
Sought information on event	28.9	21.1	25.0	24.6
Collected belongings	8.9	24.6	16.7	17.5
Provided verbal instruction to evacuate	15.6	19.3	4.2	15.1
Initiated evacuation	11.1	8.8	12.5	10.3
Waited for further information/instruction	17.8	5.3	0.0	8.7
Active protective action (self and others)	4.4	5.3	16.7	7.1
Grouped together	4.4	5.3	4.2	4.8
Gathered or made emergency equipment	2.2	1.8	4.2	2.4
Continued to work	2.2	3.5	0.0	2.4
Provided information to external source	0.0	1.8	8.3	2.4
Provided assistance—verbal	0.0	1.8	4.2	1.6
Act of normal routine prior to evacuation	2.2	0.0	0.0	0.8
Provided safety instructions	2.2	0.0	0.0	0.8
Searched (physical and verbal)	0.0	1.8	0.0	0.8
Provided information to emergency services	0.0	0.0	4.2	0.8

Table 5
Second response activities in WTC1.

Second activities	Floor cluster			
	Lower (1–42) % (n=45)	Central (43–76) % (n=57)	Upper (77–110) % (n=24)	All floors % (n=126)
Sought information on event	6.6	8.8	16.7	9.5
Collected belongings	20.0	12.3	8.3	14.3
Provided verbal instruction to evacuate	8.9	7.0	16.7	9.5
Initiated evacuation	40	28.1	12.5	29.4
Waited for further information/instruction	0.0	10.5	0.0	4.8
Active protective action (self and others)	2.2	3.5	4.2	4.0
Grouped together	2.2	3.5	12.5	4.8
Gathered or made emergency equipment	2.2	1.8	0.0	1.6
Continued to work	0.0	1.8	0.0	0.8
Provided information to external source	2.2	0.0	8.3	2.4
Provided assistance—verbal	2.2	1.8	4.2	2.4
Provided information to internal source	2.2	0.0	0.0	0.8
Act of normal routine prior to evacuation	0.0	5.3	0.0	2.4
Provided safety instructions	0.0	1.8	4.2	1.6
Searched (physically and verbally)	0.0	5.3	0.0	2.4
Provided information to emergency services	0.0	0.0	0.0	0.0
Evacuated at previous activity	11.1	8.8	12.5	10.3

It is also apparent that participants located in the lower floor cluster were more likely to 'wait for further information/instruction' (17.8%) than those in the central (5.3%) and upper floor cluster (0%). Fisher's exact test results indicate that these differences were significant (p=0.04 and p=0.03, respectively). It is also apparent that 'seeking information' was slightly more prevalent in the lower cluster, although the differences between the lower and other clusters were not significant.

Despite other differences not being statistically significant, the descriptive statistics appear reasonable and consistent with the information on cues received provided previously in Table 3. For example, a greater proportion of those in the upper floor cluster 'provided information to external sources' and took 'active protective action' than those in the central and lower floor clusters, and those in the lower cluster were more likely to wait for further information, actions reflective perhaps of the cues and the severity of the cues received. However, more unpredictable was that the greater proportion of those located in the central floor cluster reported 'collecting belongings' as an initial activity than both the lower and upper clusters.

5.5. Other activities

As noted previously, all reported activities were coded and reduced to create specific usable categories. The coding system and processes used for the initial activities were also used to determine the second and third activities of occupants across floor clusters. The second and third activities are presented in Tables 5 and 6, respectively.

From Tables 5 and 6 it is apparent that the most common second and third action across floor clusters was to 'initiate evacuation' (29.4%), i.e. many did not engage in other activities that might have delayed their evacuation. The second most frequent action was 'collected belongings' (14.3%), i.e. an activity that would suggest preparation to evacuate. Interestingly a smaller percentage of occupants on the upper cluster initiated evacuation as a second action compared with the other clusters (12.5% compared with 28.1% in the central cluster and 40% in the lower cluster). Other common second actions in the upper cluster that were not so apparent in the other clusters were to 'provide instruction to evacuate' (16.7%), i.e. encourage others to leave and 'group together'. This would suggest that in the early stages there

Table 6
Third response activities in WTC1.

Third activity	Floor cluster			
	Lower (1–42) % (n=45)	Central (43–76) % (n=57)	Upper (77–110) % (n=24)	All floors % (n=126)
Sought information on event	2.2	1.8	0.0	1.6
Collected belongings	11.1	10.5	12.5	11.1
Provided verbal instruction to evacuate	4.4	5.3	0.0	4.0
Initiated evacuation	22.2	26.3	33.3	26.2
Waited for further information/instruction	0.0	1.8	0.0	0.8
Active protective action (self and others)	0.0	0.0	0.0	0.0
Grouped together	0.0	1.8	8.3	2.4
Gathered or made emergency equipment	4.4	0.0	4.2	2.4
Continued to work	0.0	0.0	0.0	0.0
Provided information to external source	0.0	5.3	4.2	3.2
Provided assistance—verbal	0.0	1.8	0.0	0.8
Act of normal routine prior to evacuation	2.2	0.0	0.0	0.8
Provided safety instructions	0.0	0.0	0.0	0.0
Searched (physically and verbally)	2.2	5.3	0.0	3.2
Provided information to emergency services	0.0	0.0	8.3	1.6
Evacuated at previous activities	51.1	36.9	25.0	39.7
Provided information to internal source	0.0	0.0	0.0	0.0
Provided assistance—physically	0.0	3.5	4.2	2.4

Table 7
Global activities in WTC1 by floor cluster.

Global activities	Floor cluster			
	Lower (1–42) % (n=45)	Central (43–76) % (n=57)	Upper (77–110) % (n=24)	All floors % (n=126)
Sought information on event	33.3	28.1	33.3	31.0
Collected belongings	46.7	59.6	37.5	50.8
Provided verbal instruction to evacuate	33.3	31.6	29.2	31.7
Waited for further information/instruction	17.8	15.8	8.3	15.1
Active protective action (self and others)	8.9	8.8	29.2	12.7
Grouped together	6.7	14.0	29.2	14.3
Gathered or made emergency equipment	13.3	10.5	16.7	12.7
Continued to work	4.4	3.5	0.0	3.2
Provided information to external source	4.4	7.0	20.8	8.7
Provided assistance—verbal	6.7	8.8	16.7	9.5
Act of normal routine prior to evacuation	4.4	10.5	0.0	6.3
Provided safety instructions	2.2	5.3	4.2	4.0
Searched (verbal/physical)	8.9	14.0	4.2	10.3
Provided information to emergency services	0.0	0.0	12.5	2.4
Provided information to internal source	4.4	0.0	4.2	2.4
Provided assistance physical	0.0	5.3	4.2	3.2
Physically removed people from situation	4.4	0.0	0.0	1.6

Note: Totals do not add up to 100% as participants may have completed multiple activities.

was perhaps more reliance on each other in dealing with the situation that had arisen.

Aggregating the figures presented in Tables 4–6 also indicates that 58.3%, 63.2% and 73.3% of occupants of the upper, central and lower clusters, respectively, initiated evacuation as one of their first three responses. This indicates that a greater proportion of those on upper floors conducted more than two pre-evacuation activities in comparison with the other clusters and may be suggestive of the more complex response necessary by those on the upper cluster in dealing with the prevailing conditions.

It should be noted, that the second and third activities presented in Tables 5 and 6 are meaningful only to the extent that they give a very general flavour of when activities were conducted. In reality, the activities are not necessarily conducted at the same time, i.e. one individual's second or third activity is not necessarily conducted at the same time as another individual's. Furthermore the second and third activities of an individual are expected to be dependent on their previous activity. The inter-relationships between activities can really be explored only using more complex statistical modelling techniques, which are beyond the scope of this paper.

In order to understand general behaviour in the response phase more fully, the prevalence of each activity in each cluster, regardless of when the activity was conducted within the recognition and response phase, was explored. Table 7 provides details of participants' 'global activities', i.e. the numbers and percentages of those who undertook a particular activity at any time throughout the entire recognition and response phase.

From Table 7 it is apparent that the most prevalent activity across the whole sample during the response phase, was 'collected belongings' with just over half of all participants reporting collecting belongings at some stage during the response phase, followed by: 'provided verbal instruction to evacuate' (31.7%) and 'sought information on the event' (31.0%).

However, differences are apparent in the prevalence of global activities across floor clusters. For example, although 'collected belongings' was the most prevalent activity across the sample, it was more prevalent in the central cluster (59.6%).

Table 7 indicates a number of activities that were more prevalent in the upper floor cluster, namely 'grouped together' (29.2%), 'gathered or made emergency equipment' (16.7%), took 'active protective action' (29.2%), 'provided information to external sources' (20.8%) and 'provided information to emergency services' (12.5%). These actions are perhaps not surprising given the more extreme conditions experienced on upper floors. It is also interesting that none of the participants from the upper floor cluster reported having completed an 'act of normal routine prior to evacuation' or 'continued to work' at any stage during the response phase in comparison with a small proportion of participants located in the central and lower floor clusters.

Significance testing indicated that the proportion of participants in each floor cluster differed significantly in relation to taking 'active protective action' ($\chi^2(2)=7.25$, $p=0.03$, two tailed) and 'grouping together' ($\chi^2(2)=6.48$, $p=0.04$, two tailed). Pairwise comparisons using Fisher's exact test on those proportional differences found that significantly greater proportions of participants located in the upper floor cluster performed 'active protective action' in comparison with participants located in the lower ($p=0.04$) and central floor clusters ($p=0.03$). Fisher's exact test also indicated that participants located in the upper floor cluster were significantly more likely to 'group together' than the lower floor cluster ($p=0.02$) with a trend difference evident between the upper and central floor clusters ($p=0.10$) in this respect. Significant differences between the upper and lower floor cluster in relation to 'providing information to external sources' ($p=0.05$), and trend differences between the upper and central floor clusters ($p=0.08$) were also found. In addition, a trend difference was evident between the proportion of participants in the central floor cluster who 'collected belongings' compared with the upper floor cluster ($p=0.06$).

5.6. Recognition and response time

Recognition and response refers to *"the time from when an occupant receives the first cue until they start to move towards an exit"*. As noted previously, the HEED database contains estimations of participants' response times relative to known global time markers, i.e. T1 (WTC1 impact, 08:47), T2 (WTC2 impact, 09:03) and T3 (WTC2 collapse, 09:59). The response time distribution for all WTC1 participants as extracted from the HEED database is shown in Fig. 4. Fig. 5 depicts the response time by floor cluster. The majority of participants (84.4%, $n=107$) initiated evacuation, i.e. moved towards an exit, within 8 min of the WTC1 impact (Fig. 4). The remaining 15.6% ($n=19$) took more than 8 min to begin their evacuation with just over half of this group evacuating 'closer to T2 than T1' i.e. between 08:55 and 09:03 or 8–16 min after the first impact (7.9%, $n=10$). From Fig. 4 it is apparent that 4% ($n=5$) of participants did not respond until after WTC2 was hit, i.e. more than 16 min after the initial impact on WTC1. It can be seen that three of these late responders were located in the upper floor clusters, with the remaining two participants located in the central and lower floor clusters.

The participants located in the upper floor clusters who did not evacuate until after the impact on WTC2, were prevented from evacuating due to thick smoke and/or flames on their floor. However, the reasons for the delayed evacuation of the participants on the lower and central floors were very different, i.e. it seems that they simply did not perceive themselves to be at personal risk at the time of the impact, albeit that they experienced the impact phenomena.

5.7. Perception of risk

The participants were invited to rate how much risk they perceived on a seven-point Likert scale at 'impact' (when the participants' first became aware that something unusual had occurred) and at 'evacuation' (just as they had initiated their

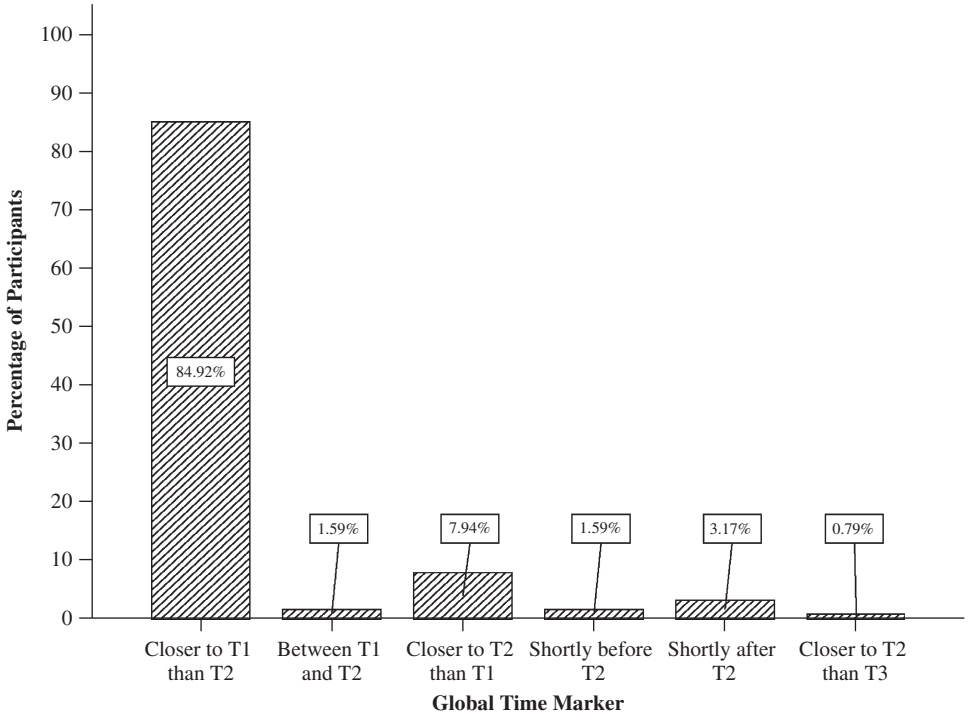

Fig. 4. Participants' response times.

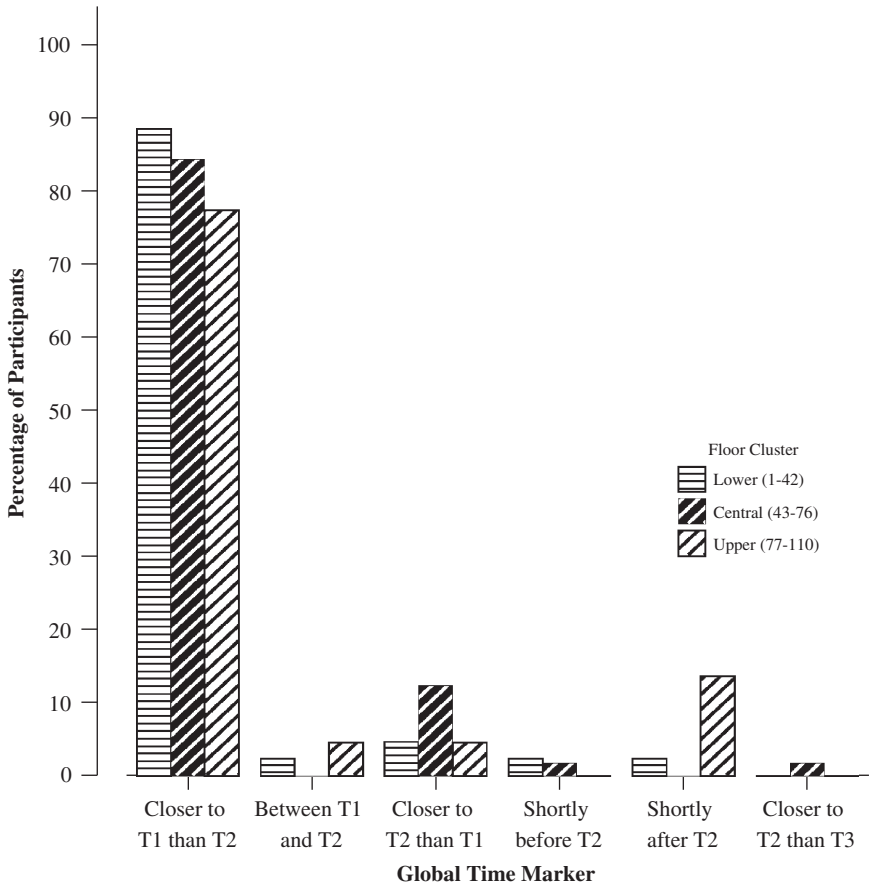

Fig. 5. Participants' response times by floor cluster.

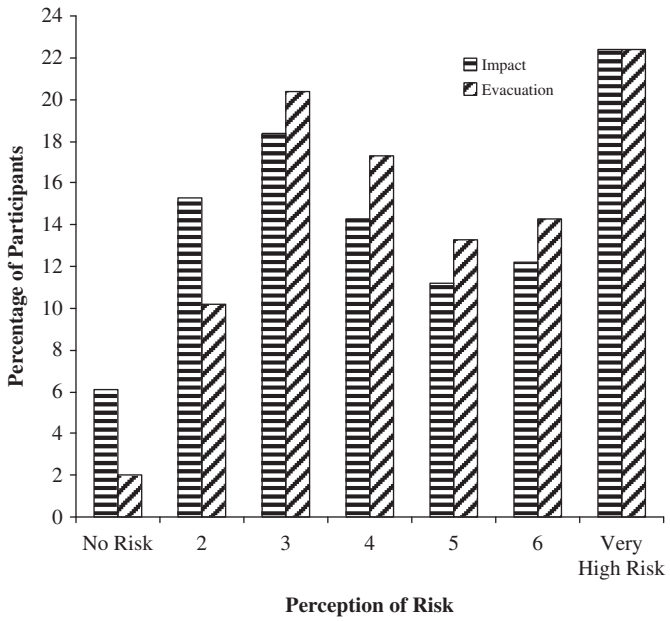

Fig. 6. Perception of risk at impact and at time of evacuation.

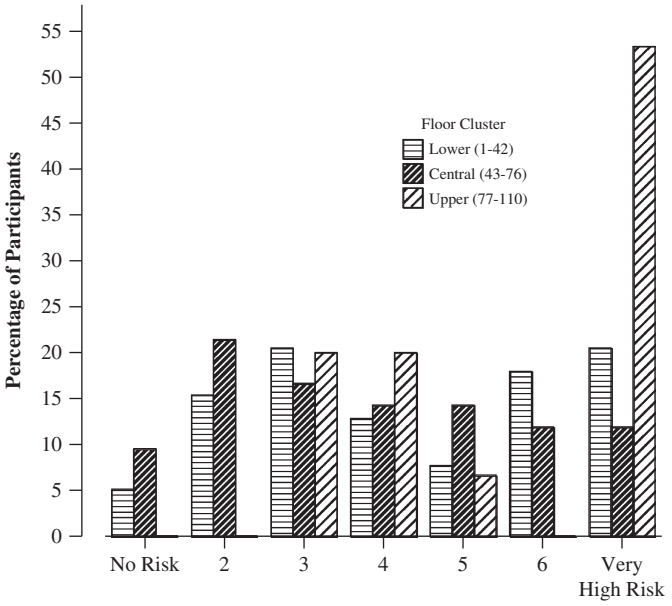

Fig. 7. Participants' perception of risk across floor clusters at impact.

evacuation). On this scale '1' represented 'no risk' and '7' represented 'very high risk'. Fig. 6 shows the participants' risk perception scores and indicates that the majority of participants scored at the upper end of the scale, i.e. 'very high risk' at both time points. Over time the risk perception profiles became more negatively skewed, indicating that the percentage of participants perceiving higher risk increased as they moved through the recognition and response phase. This observation was confirmed using the Spearman's rho correlation coefficient, which indicated a strong positive significant correlation between risk perception across the two administrations over time (rho=0.67, $p < 0.01$, two tailed).

Table 8
Perception of risk scores across floor clusters.

Floor cluster	Perception of risk	No. of participants	Minimum	Maximum	Median	Mean	Standard deviation
Lower (1–42)	Impact	39	1	7	4	4.38	1.97
	Evacuation	38	1	7	5	4.74	1.80
Central (43–76)	Impact	42	1	7	4	3.86	1.91
	Evacuation	43	1	7	4	4.28	1.67
Upper (77–110)	Impact	17	3	7	7	5.53	1.70
	Evacuation	17	2	7	5	5.24	1.92

The participants' risk perception profiles across floor clusters at 'impact' are shown in Fig. 7. The participants located in the lower and central floor clusters scored across the entire range of the risk perception scale, whilst participants in the upper floor cluster did not score under '3' with the majority (52.9%, $n=9$) scoring risk as very high.

Table 8 presents detailed comparisons of risk perception across floor clusters. From Table 8 it can be seen that participants located on upper floors rated their risk on average greater at both 'impact' and 'evacuation' than participants located in the central and lower floor clusters. The rated risk perceptions of participants in the central and lower floor clusters were similar in magnitude with both displaying slight increases between 'impact' and 'evacuation'. In contrast, the mean perception of risk scores for upper floor participants decreased slightly between 'impact' and 'evacuation' administrations.

The differences in the thoughts of those on lower and upper floors are perhaps best illustrated in the words of participants themselves. For example, one participant located on the 13th floor when asked to rate how much risk he/she felt at that time, i.e. impact, said:

> *"didn't really enter my mind that there was any risk at the moment, you know the noise was just very sudden and at that point it could have been … a steam explosion or something... I wasn't thinking in terms of risk, no risk"*

The participant's reasoning for this was that "*It hadn't dawned on me that there was, it was a risk, it was a bad situation but I didn't think I was personally at risk as soon as I heard the sounds cos I didn't know I was hurt yet.*"

However, the same participant when asked to rate his/her perception of risk at the point when he/she decided to evacuate rated it as high—"*… because by then I think a lot of situational awareness had kicked in*".

In contrast, a participant located on the 77th floor (lower floor of the upper cluster) indicated that when he/she heard "*the big bang… the building started to shake… it rocked*" and indicated risk at impact as "*Quite high risk… because with the shaking of the building those floors could have toppled*".

Kruskal–Wallis Test indicated that the participants' floor cluster was a significant factor in perception of risk at initial impact ($\chi^2(2)=9.28$, $p=0.01$) but not at the decision to evacuate ($\chi^2(2)=3.65$, $p=0.16$). Pairwise comparisons indicated that participants located in the upper floor cluster scored significantly higher on the perception of risk scale at initial impact than the participants in the lower floor cluster (Mann–Whitney $U=211.50$, $p=0.01$, one tailed) and central floor cluster (Mann–Whitney $U=182.00$, $p=0.02$, one tailed).

The potential relationships between the scores on the risk perception scale across the two time points (impact and evacuation) were investigated. Table 9 shows the results obtained with significantly strong positive correlations between perception of risk at impact and evacuation for the participants located in the lower and central floor clusters. However, no significant correlation was found for participants located in the upper floor cluster.

Table 9
Perception of risk correlations in relation to floor clusters.

.Floor cluster	Perception of risk at impact and evacuation	
Lower (1–42)	Spearman's Correlation	0.78**
	N	38
Central (43–76)	Spearman's Correlation	0.64**
	N	42
Upper (77–110)	Spearman's Correlation	0.18
	N	15

**Correlation is significant at the 0.01 level (two tailed).

5.8. Relationship between risk perception and initial/global activities

Analyses of risk in terms of activities conducted by the participants revealed statistically significant differences. Participants who reported 'continuing to work' as an initial activity subsequent to the impact were found to have significantly lower risk perception than participants who did not continue to work ($U=52.50$, $p=0.03$, one tailed). Furthermore, analyses of the global activities in relation to risk perception at initiation of evacuation found that participants who omitted to 'collect belongings', 'grouped together' and 'provided information to emergency services' had significantly higher perception of risk ($U=972.50$, $p=0.05$, one tailed; $U=417.00$, $p=0.02$, one tailed; $U=46.50$, $p=0.02$, one tailed, respectively) than those who did not.

6. Discussion of results obtained

The focus of this paper is on the recognition and response phase of evacuees following the impact on WTC1. The participants' recognition cues, response activities and perception of risk were studied using information extracted from HEED. As noted previously, the HEED sample was well stratified across floors, thus allowing useful comparisons between the responses of participants by floor cluster. The sample was also similar in terms of demographics to the estimates of the population of WTC1 on 9/11 made by NIST [2] and to the larger sample used in the University of Columbia study [3].

It must be emphasised, however, that this incident is not considered representative of a typical fire in a building, as fires in buildings were understood prior to 9/11, i.e. this was a large-scale terrorist attack on high-rise buildings using large commercial aircrafts. This is evident from the nature of cues received and by immediate responses of the evacuees of WTC1, particularly those located in proximity to the impact zone. Furthermore, it is important to note that at no time were any fire alarms sounded

in WTC1. The cues received by many participants in this event could not be considered characteristic of a typical fire incident, and therefore care should be taken in generalising the findings in terms of prevalence of response activities to other fire situations.

In this study almost 100% of participants stated that they 'felt the impact', just under two thirds of the participants stated that they 'heard the impact', while less than 9% stated that they 'saw fire or smoke internally'. Whilst the findings reported in this study are not directly comparable with the NIST study [2] (NIST reported on the first cue received whilst this study considered the first set of cues), comparison on the first cue only suggests that the percentages of participants reporting feeling or hearing the impact are similar, i.e. 97% and 93%, respectively.

Comparisons made between floor clusters in this study indicated that a greater proportion of participants in the upper floor cluster heard the impact than those located in the lower and central clusters. The differences between the upper and central floor clusters were deemed to be statistically significant. Further, a greater proportion of participants located in the upper floor cluster 'experienced internal phenomena', 'saw or heard incoming plane' and 'saw smoke/fire internally', compared with the other clusters; the latter was deemed to be statistically significant. These findings emphasise the magnitude and severity of the impact and go some way in explaining the intensity of response exhibited by participants, particularly those located on upper floors.

It is interesting to note that, despite the strong stimuli received, only 10% of the sample initiated evacuation as a first action. Not surprisingly, this was more evident in the upper floor cluster. However, if we also consider the activities that suggest an intention to evacuate, i.e. 'collected belongings' (17.5%), 'provided verbal instruction to evacuate' (15.1%), and pursued 'act of normal routine prior to evacuation' (0.8%), it is evident that close to 45% of participants immediately pursued evacuation-related activities, even though some of these activities inevitably delayed their evacuation. In addition, 58.3%, 63.2% and 73.3% of occupants of the upper, central and lower clusters, respectively, initiated evacuation as one of their first three responses. It is also interesting to note that very few (only 3%) continued to work before initiating evacuation or other activities.

An analysis of the response times of participants suggested that over 84% of participants started their evacuation within the first 8 min after the initial impact on WTC1. Just over half of the remaining participants evacuated within 8–16 min after the initial impact, whilst approximately 4% of participants did not respond until after WTC2 was hit, i.e. more than 16 min after the initial impact on WTC1.

NIST [2] reported that occupants closer to the impact area in WTC1 delayed their evacuation for a longer period of time than occupants of the other two floor clusters. It was suggested by NIST [2] that this could have been due to fire, smoke, building damage, etc. Whilst the analysis presented here did not directly compare response times across floor clusters, it did indicate lengthy delays for a small number of people in the upper floor cluster. The transcripts of participants located in the upper floor cluster who delayed evacuation (after the impact on WTC2) indicate that they were prevented from immediately evacuating because of the prevailing environmental conditions in the WTC1, e.g. thick smoke and/or flames. Other participants were delayed by following the instructions of others and waiting for assistance. Furthermore, as noted above, the percentage of occupants on the upper cluster who initiated evacuation as one of their first three responses was less than the percentage for other floor clusters (58.3%, 63.2% and 73.3%, respectively). This suggests that a more complex response by those on the upper cluster was necessary in order to deal with the prevailing environmental conditions.

Analysis of the initial response activities indicated differences between floor clusters, some of which were determined to differ significantly. For example, the proportion of participants located in the lower floor cluster who initially 'waited for further information/instruction' was significantly greater than the proportion of participants located in the upper and central floor clusters. It may be that those located on lower floors simply felt less urgency to evacuate. Examination of the risk scores indicate that the lower floor cluster had lower risk scores in comparison with the upper floor cluster, but those in the central cluster were lower again. Therefore, it is possible that other factors, e.g. the amount or value of information available to them, may have had an effect; this seems to be confirmed by the finding that a greater percentage of participants in the lower cluster 'sought information on the event' as an initial activity compared with the other clusters. Consequently, the combination of lower perception of risk and less information may have increased the likelihood of those located in the lower floor cluster to respond by 'waiting on further information/instruction'.

As noted previously some initial activities were more prevalent in the upper cluster compared with the other clusters, i.e. 'provided information to external sources', took 'active protective action' and 'provided verbal instruction to evacuate'. These differences can be explained by the fact that participants in the upper floor cluster were in closer proximity to the impact zone, and therefore would be expected to have greater awareness of the seriousness of the event and their survival needs.

A comparison of the global activities from this study with the activities prior to evacuation reported by NIST [2] indicates similarities. For example, similar proportions of participants 'collected belongings' (50% and 46%, respectively), 'sought information' (31.5% and 28%, respectively), and 'continued to work' (3.2% and 3%, respectively). The percentages conducting the activity defined in this study as 'act of normal routine prior to evacuation', which included locking office door, switching off electrical appliances, using toilets, locking away item and shutting down computers, were found to be similar to NIST's category of 'shut down computer' (6.5% and 6%, respectively).

Analysis of the global activities also indicated differences between floor clusters. For example, the 'act of normal routine prior to evacuation' and 'continuing to work' were non-existent in the upper floor cluster, which is perhaps not surprising given the range and severity of cues experienced by those near the impact zone. 'Collecting belongings' and 'provided verbal comment to evacuate' were also less prevalent in the upper floor cluster. However, 'grouped together', 'gathered or made emergency equipment' and pursuing 'active protective action' were more prevalent. For example, results indicated that just under a third of participants located in the upper floor cluster reported conducting, at some time during the response phase, an act of 'active protective action' compared with approximately only 9% of participants located in the central and lower floor clusters. Furthermore, approximately 30% of participants located in the upper floor cluster reported 'grouping together' compared with only approximately 7% and 14% on the lower and central clusters, respectively. These outcomes were found to be statistically significant.

Participants located on upper floors also had a higher perception of risk than those in the other floor clusters at both impact and initiation of evacuation. Once again, considering the participants' proximity to the impact, this outcome is not surprising. As noted previously, participants on the upper floors were more likely to experience particular cues than those on the other floor clusters. This was true for four out of the seven cue categories ('heard impact', 'experienced internal phenomena', 'saw or heard incoming plane', 'saw smoke/fire internally'). Even

though the intensities of these cues are indeterminate, the cues can be reasonably considered to be of greater intensity, frequency and diversity on upper floors, as evidenced by the participants' recollections from within the transcripts.

Results have indicated that risk perception may actually have had a positive effect with regard to the activities pursued by participants. Throughout the recognition and response phase, the perceptions of risk were significantly higher for participants who reported 'not continuing to work', 'not collect belongings', 'grouping together' and 'providing information to emergency services'. Therefore, heightened risk perception may inhibit participants from carrying out activities that delay evacuation, e.g. 'continuing to work', 'collect belongings', and promote pro-active activities, e.g. 'grouping together'.

Interestingly, correlations indicated that risk perception increased significantly during the recognition and response phase. Analysis of risk over time indicated significant increases for the lower and central floor clusters. However the upper floor cluster did not display such significant increases; this may have been due to the already elevated level of risk perception at impact in comparison with other floor clusters.

7. Conclusions

Detailed information relating to WTC1 and WTC2 evacuees' experiences and activities has been captured, collated and archived in a relational High-rise Evacuation Evaluation Database (HEED). Information accessed from the HEED was used to investigate evacuees' experiences and activities in WTC1, during the recognition and response phase of their evacuation.

The sample of participants in this study was fairly uniformly distributed across the lower, central and upper floor clusters. The sample was also similar in terms of demographics to the estimates of the population of WTC1 made by NIST [2] and similar to the demographics of participants in the University of Columbia study [3].

The results indicate that the most prevalent cues received by participants in all floor clusters were felt and heard the impact. It was found that significantly more participants in the upper floor cluster experienced seeing fire/smoke internally and hearing the impact in comparison with those located in the central floor cluster.

Despite the magnitude, volume and intensity of the cues received, only 10% of the sample initiated evacuation as an initial response. However, analysis suggests that over 45% of participants immediately initiated activities in preparation for evacuation. Notwithstanding, a large percentage of occupants did not immediately initiate evacuation-related activities, with the most frequently occurring initial response in all floor clusters being to 'seek information on event'.

Overall, approximately 85% of participants initiated evacuation within 8 min of the WTC1 impact. Most participants did not waste time on delaying activities, e.g. waiting on information/instruction. Where delays in evacuation were reported, these were mainly due to prevailing environmental conditions, following the instructions of others and waiting on help.

Differences in the responses of participants by floor clusters have been identified and it is suggested that these can be explained, at least in part, by differences in the intensity/frequency of cues received. In particular it was found that those in the upper cluster were:

- significantly more likely to conduct 'active protective action' compared with those located in the lower and central floor clusters;
- significantly more likely to 'group together' than those located in the lower floor cluster; trend differences were observed between the upper and central floor clusters and
- significantly more likely to 'provide information to external sources' compared with the central floor cluster; trend differences were observed between the upper and lower floor clusters.

Differences in the perception of risk between the floor clusters were also identified:

- participants located in the upper floor cluster had a higher perception of risk at both initial impact and initiation of evacuation than those in the central and lower clusters and
- participants located in the upper floor cluster had a significantly higher perception of risk at initial impact compared with the central floor cluster.

Risk perception increased significantly over time, i.e. during the recognition and response phase, for both the central and lower floor clusters, although this was not evident for participants in the upper cluster, perhaps due to their already elevated perception of risk.

Analyses of risk in terms of activities conducted by the participants revealed statistically significant differences:

- participants who 'continued to work' and 'collected belongings' as an initial activity were found to have significantly lower risk perception scores than those who did not and
- participants who 'grouped together' and 'provided information to emergency services' had significantly higher perception of risk at initiation of evacuation than those who did not.

The evacuation of WTC1 on 9/11 was as a consequence of terrorist attacks with catastrophic effects. For this reason, care should be taken when generalising the findings of this study, with respect to likelihood of performing various response activities, to other fire events. In this event a number of principal cues were uncharacteristic of typical fire incidents, and whilst some of the resulting activities, e.g. 'collecting belongings' and 'waiting for information', are activities that have long been recognised as characteristic response behaviours in fire, others may not be considered as typical in the response phase of most fires, e.g. 'provided information to external sources', 'gathered or made emergency equipment' and 'took active protective action'. This study does, however, provide insights into the range and complexity of the behaviour of occupants of WTC1 on 9/11 and, in an age of global terrorism, provides insights into the potential behaviours of people in other catastrophic incidents. The results are also significant in that they suggest that the propensity to undertake certain actions is related to the risk perceived by evacuees, which in turn is related to the cues (nature and severity) received. The ability to reliably predict an individual's perception of risk as a function of cues received in a particular fire incident and relate this to individual behaviour is an important area for future human behaviour in fire research.

Acknowledgements

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