Safety Science 129 (2020) 104837

Contents lists available at ScienceDirect

Safety Science

journal homepage: www.elsevier.com/locate/safety

人们如何在地震和震后疏散中做决定:在沉浸式虚拟现实中使用语言协议分析

How people make decisions during earthquakes and post-earthquake evacuation: Using Verbal Protocol Analysis in Immersive Virtual Reality

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ARTICLE INFO

Keywords:
Immersive Virtual Reality
Earthquake evacuation
Decision-making
Behavioral analysis
Verbal Protocol Analysis
Think-aloud protocol analysis

ABSTRACT

Human behavior during earthquakes and post-earthquake evacuation is crucial to earthquake safety. Understanding decision-making processes may explain why people respond in different ways to earthquakes. This information can assist with the development of earthquake evacuation guidelines and practices. Verbal Protocol Analysis (VPA) can be used to investigate decision-making processes. VPA encourages participants to think aloud while they are executing tasks. However, it is difficult to obtain such data during actual earthquakes or traditional evacuation drills. Immersive Virtual Reality (IVR) is an innovative tool that can be applied to investigate human behavior under extreme conditions such as earthquakes. In this study, we used a head-mounted display (HMD)-based IVR for investigating decision-making processes during an earthquake emergency based in Auckland City Hospital. A total of 83 hospital staff and visitors completed the experiment. VPA was carried out along with the IVR. The responses of VPA were analyzed to identify decision-making themes. Results show that participants tended to be influenced by other people, especially those in authority positions, and wanted to accompany other people while evacuating. Participants were also found to have wait-or-flight responses in post-earthquake evacuation. Implications for current earthquake evacuation guidelines and practice are provided based on the results.

1. Introduction

Appropriate behavioral response to earthquakes and post-earthquake evacuation is a key factor in decreasing casualties and losses that result from non-structural damage (Cin and Değirmençay, 2018; Coburn et al., 1992). Behavioral guidelines recommend the actions building occupants should take during earthquakes and post-earthquake evacuation. In New Zealand, building occupants are recommended to "Drop, Cover and Hold" during earthquakes and to carry out actions such as help others, check for and extinguish small fires, and listen to radio stations during post-earthquake evacuation (Mahdavifar et al., 2009; New Zealand Ministry of Civil Defence & Emergency Management, 2015; Stuart-Black, 2015). Such guidelines rely heavily on the realistic appraisal of evacuation behavior during earthquake emergencies.

Behavior is the result of cognitive and decision-making processes (Aarts et al., 1998). In that regard, investigating cognitive and decision-making processes can provide insights into evacuation behavior. However, to date, few studies have addressed how building occupants make decisions during earthquakes and post-earthquake evacuation.

Generally, there are two types of analyses to investigate decision and choice data, namely stated preference and revealed preference (Hensher and Bradley, 1993; Mark and Swait, 2004). Stated preference includes surveys and interviews that are carried out after the occurrence of emergencies (Arnold et al., 1982; Saunders, 1997). However, stated preference analysis generates retrospective reports that may suffer from recall bias that can lead to misleading information (Hassan, 2006; Raphael, 1987). Additionally, threats such as earthquakes are

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https://doi.org/10.1016/j.ssci.2020.104837
Received 3 October 2019; Received in revised form 11 May 2020; Accepted 13 May 2020
Available online 21 May 2020

acute stressors which may impair memory retrieval (Dominique et al., 2009; Neupert et al., 2006). Revealed preference has also been introduced to analyze behavior and decision-making during emergencies by observing recordings made by cameras such as Closed Circuit Television (CCTV) (Lambie et al., 2017; Zhou et al., 2018). Most of the understanding on how people behave during earthquakes has been achieved by analyzing CCTV videos or videos available on social media, see for instance (Bernardini et al., 2016; Bernardini et al., 2019; Lambie et al., 2016). In this way, the output of decision-making, which is executed behavior, is explicit. However, the reasoning behind the behavior is implicit and has to be interpreted by researchers, which can lead to bias too. Together, an alternative approach is therefore suggested to investigate ongoing decision-making processes, namely Verbal Protocol Analysis (VPA). VPA is used concurrently with task execution and aims to generate insights into how courses of actions are actually selected and executed. By verbalizing thoughts, the decision-making processes employed during the courses of actions are elicited without scrutiny.

In catastrophic events, concurrent data collection cannot be planned. An alternative approach is to use evacuation drills. Evacuation drills provide building occupants with opportunities to practice evacuating buildings in the case of emergencies (Gwynne, Kuligowski, Boyce, Nilsson, Robbins, Lovreglio et al., 2017). Evacuation drills have been used as a resource to collect data for behavioral analysis (Gwynne, 2010; Proulx et al., 1996). Evacuation drills can be described as a model of building evacuation that includes a number of simplifications such as simplified hazardous events, evacuee population, and evacuee responses (Averill et al., 2011; Fioretti, 2013; Kuligowski et al., 2017). The outcomes of evacuation drills rely on these simplifications, and as such have limited ability to reflect real-world scenarios (Gwynne et al., 2016; Gwynne et al., 2017). This limitation means that the behavior yielded by drills may be different from the behavior that would occur during an actual evacuation event (Yang et al., 2011). Berlin and Carlström (2015) argued that building occupants only performed simple actions during evacuation drills instead of adapting themselves to changing circumstances because of the unrealistic scenarios presented by drills. Therefore, there is a need to look for a more credible source of evacuation behavioral and cognitive data.

Immersive Virtual Reality (IVR) represents an innovative technique that has the possibility to deliver realistic virtual evacuation drills, thereby reducing the gap between drills and real-world scenarios (Lovreglio et al., 2017). IVR allows participants to be fully immersed in simulated environments generated by computers. IVR promotes realistic scenarios, including threats and hazards that are too dangerous for participants to be exposed to (Feng et al., 2018a). In a recent study, participants reported a high level of sense of presence because of the realistic environment and simulation presented by IVR (Lovreglio et al., 2018). The close-to-reality simulation makes it possible to investigate human behavior and decision-making processes under dangerous conditions (Gao et al., 2019; LaValle, 2017; Sherman and Craig, 2018).

Ecological validity is a measure of how experimental methods, materials, and setting represent real-world scenarios (Brewer and Crano, 2000). Several studies have investigated the ecological validity of IVR. In most cases, IVR delivers visual and audio simulation as the ability to simulate other features such as physical touch and olfactory cues is limited (Kinateder et al., 2014c). As such, Kinateder et al. (2014c) argued that the ecological validity of IVR is less than real-world cases due to it being a laboratory setting with an abstraction of the real world. However, results suggest that IVR still has a relatively high ecological validity; and benefits from the ability to induce behavioral and emotional responses similar to the real world (Heliövaara et al., 2012; Kobes et al., 2010; Shechtman et al., 2009; Törnros, 1998). These findings are supported by Peperkorn et al. in that emotional reactions can be triggered by perceptual cues such as visual stimuli (Peperkorn et al., 2014). Other than ecological validity, Kinateder et al. (2014c) argued that IVR permits higher external and internal validity than traditional laboratory experiments and real-world cases due to high-level of experimental control. Similarly, Loomis et al. (1999) stated that IVR offers higher experimental control and ecological validity in comparison with other conventional methods. Therefore, IVR has been suggested as an alternative laboratory tool to conduct behavior and cognition studies (Kinateder et al., 2014c; Loomis et al., 1999).

The aim of this study is to investigate how building occupants make decisions during earthquakes and post-earthquake evacuation, using VPA in IVR. Research questions include 1. What are the actions and decisions that staff members and visitors make during an earthquake and post-earthquake evacuation process in a hospital building? 2. What are the differences in terms of actions and decisions between staff and visitors at different stages of the related evacuation process? A detailed review of VPA and IVR for evacuation studies is outlined first. Following that, a case study based on Auckland City Hospital is presented, including the design and development of the IVR scenario. Participants and analysis are discussed in two groups, which are staff members and visitors, as staff members are expected to be more prepared for emergencies. Finally, preliminary findings and implications for earthquake safety guidelines and practice are discoursed.

1.1. Verbal Protocol Analysis

Why do people take the actions they do during earthquakes and subsequent evacuation? In order to understand the decision-making processes, Verbal Protocol Analysis (VPA) has been introduced as a cognitive task analysis tool (Ericsson and Simon, 1980). In VPA, subjects are required to "think aloud" while engaging in problem-solving. Verbal protocols are the thoughts being immediately verbally expressed (Ericsson, 2006). VPA offers a way to reflect the reasoning underlying decision-making and thought processes in the course of performing actions (Cornelissen, 2013). VPA has been used to examine a wide range of human factor constructs, such as situational awareness (Salmon et al., 2013), distraction (Young et al., 2013), problem-solving (Isenberg, 1986), and decision-making (Barber and Roehling, 1993; Bettman and Park, 1980) in a range of domains and complex systems. VPA also has been applied to study behavior in emergency situations (Banks et al., 2014) and cognitive strategies in risk assessment (Svenson, 1985). In the context of this research, VPA has the capability to uncover what a building occupant is thinking and their reasoning during earthquakes and post-earthquake evacuation.

Ericsson and Simon (1980) identified two types of verbal protocols: concurrent verbal protocols and retrospective verbal protocols. Concurrent protocols are collected during task execution, whereas retrospective protocols are collected during immediate recall following task execution (Ericsson and Simon, 1980). Kuusela and Pallab (2000) found that subjects were able to produce more protocol segments under concurrent conditions as compared to retrospective conditions. One possible reason is that short-term memory fails over time (Kuusela and Pallab, 2000) and subjects need cues in short-term memory to retrieve previous thoughts from long-term memory traces under retrospective conditions (Ericsson and Simon, 1993). Kuusela and Pallab (2000) also suggested that concurrent protocols provided more insights into decision-making processes, whereas retrospective protocols might be more focused on the final choices and the outcomes of tasks. Similarly, Banks et al. (2014) and van Gog et al. (2005) found that retrospective protocols had less richness of information in terms of cognition in real-time as compared to concurrent protocols.

The performance of retrospective protocols is debated. Gero and Tang (2001) found that both concurrent and retrospective protocols produced similar outcomes for the study of process-oriented design. Ericsson and Simon (1993) pointed out that retrospective protocols were still reliable if they were generated immediately after completion of short-duration tasks. This point is in line with Banks et al.'s suggestion that retrospective protocols might still be useful for short-duration tasks given that lengthy tasks would increase the risk of verbal omissions (Banks et al., 2014).

Various studies have examined the validity and reliability of concurrent and retrospective verbal protocols. Barber and Roehling (1993) claimed that no significant evidence was found in their study to support that concurrent verbal protocol process can affect participants' decisions. This finding is consistent with the point that concurrent verbal protocol process does not change decision-making processes fundamentally if participants only report their thoughts instead of explaining them (Ericsson and Simon, 1984; Ericsson and Simon, 1980). However, this is not absolute. Russo et al. (1989) and Wilson (1994) argued that verbalization is reactive and may alter the outcomes and response time of thought processes in both concurrent and retrospective conditions. In related work, participants were found to be distracted if the mental processes are difficult to verbalize or inaccessible in memory (Wilson and Schooler, 1991; Wilson and Hodges, 1992). Verbalizing thoughts concurrently may slow down decision-making processes (Biehal and Chakravarti, 1989; Kuusela and Pallab, 2000; Ransdell, 1995). Wilson (1994) therefore suggested that verbal protocol can measure conscious processing and cannot tap the content of nonconsciousness.

Apart from reactivity, another form of invalidity is nonveridicality. Nonverdicalities can be measured in two dimensions, namely forgetting (e.g., not reporting some thoughts) and fabrications (e.g., reporting thoughts that did not occur) (Russo et al., 1989). It is argued that nonverdicalites are more likely to occur in retrospective protocols (Ericsson and Simon, 1984; Nisbett & Wilson, 1977). Russo et al. (1989) found that in their study, retrospective protocols yielded significantly fewer statements than concurrent protocols, and retrospective protocols suffered from the intruded reconstructions from the recall of thought processes. These findings place retrospective protocols at the risk of veridicality.

Acknowledging the risks to validity, verbal protocols have been still suggested as a useful tool to study behavior and cognition (Austin and Delaney, 1998; Barber and Roehling, 1993; Russo et al., 1989; Wilson, 1994). To examine key decisions in real-time across multiple decision points (i.e., see Section 3.5) in earthquakes and post-earthquake evacuation, we have selected concurrent verbal protocols as the preferred method. We expected the use of concurrent protocols would reveal conscious thoughts underlying the execution of behavior, as suggested by Wilson (1994). Participants were encouraged to report their thoughts rather than explain them in order to reduce reactivity (Austin and Delaney, 1998).

1.2. IVR for evacuation studies

IVR has been applied to study various emergencies, such as fire evacuation (Arias et al., 2018; Arias et al., 2019; Cosma et al., 2016; Kinateder et al., 2014a) and earthquakes (Feng et al., 2019; Li et al., 2017). Generally, IVR has two types of outcomes that are pedagogical outcomes and behavioral outcomes (Feng et al., 2018a).

In terms of pedagogical aspect, IVR has been introduced as a training tool to teach best evacuation practices and improve personal safety (Feng et al., 2018a). For instance, Li et al. (2017) placed participants in a virtual earthquake in order to practice self-protection skills. Participants were asked to protect themselves from hazards, and their actual movement was tracked and synchronized with the proposed IVR. Results suggested that the IVR delivered better performance than traditional training tools such as safety cards and videos. Realistic simulation, real-time interaction and feedback, and engaging experience are the main reasons that IVR permits promising training outcomes as agued by Li et al. (2017).

In terms of behavioral outcomes and as a behavioral analysis tool, IVR has the ability to explore various aspects of behavior, such as behavioral compliance and behavior validation (Feng et al., 2018a). Duarte et al. (2014) conducted a behavioral compliance study using an IVR. Participants were asked to complete emergency evacuation with different types of signage provided. Evacuation behavior was recorded in order to investigate how well participants complied with the provided signage. Duarte et al. (2014) argued that their findings were in accordance with real-world research, potentially as a result of the realistic scenarios provided by the IVR simulation.

Ronchi et al. (2015) introduced an IVR to validate evacuation models. Participants' travel paths during a tunnel evacuation were tracked and compared to the hypothetical ones generated by evacuation models. Results suggested that evacuation models generally oversimplified evacuation movement. Ronchi et al. (2015) therefore suggested that IVR permits high-level quantitative validation of evacuation movement. This view is supported by Kinateder et al. (2014a), who stated that IVR enables highly experimentally controlled studies, making it an ideal laboratory tool to investigate human behavior in fire evacuation.

Taken together, these previous studies support the notion that IVR is an effective tool to conduct evacuation studies. Even so, little attention has been paid to earthquake emergencies (Feng et al., 2018a). This study introduces an IVR to investigate building occupants' decision-making processes during earthquakes and post-earthquake evacuation. A virtual earthquake drill was carried out in the IVR.

2. Methods

The present study followed several steps. The design and development of the IVR scenario are outlined in Sections 2.1 and 2.2. The human participation using VPA in the IVR scenario is discussed in Sections 2.3 and 2.4. The collection and analysis of VPA data are reported in Section 2.5.

2.1. Experimental design

In this study, we applied VPA in IVR. The proposed IVR was developed based on an existing building—Auckland City Hospital. Building Information Modelling (BIM)-based workflow was applied in order to enable high-level dynamic changes for simulating realistic earthquakes in virtual environments (Feng et al., 2018b; Lovreglio et al., 2018). A 3D building model was created using a BIM tool-Autodesk Revit (version 2017, www.autodesk.com); then, imported into a game engine-Unity (version 5.5.1, www.unity.com) for IVR development. Fig. 1 illustrates the floor plan of the virtual environment. Non-structural damage was simulated during and after the earthquake, including breaking glass panels, falling ceiling tiles, damaged electrical appliances, and toppling furniture and partition walls. Non-player Characters (NPCs) were used to represent other building occupants inside the IVR environment. Pre-defined scripts controlled the behavior of NPCs. The detailed use of NPCs can be found in the description of the storyline, in the next paragraph. Participants were able to explore the IVR environment freely by holding a button on a remote controller to move in the facing directions. Participants were also able to crouch by clicking a button on the remote controller when they were looking down. More details of the development of the IVR can be found in Lovreglio et al. (2018). The IVR scenario is available for research via a Google drive link (https://drive.google.com/open?id=1QebeMi4CRRqssLYyXPEagyiB-BB6630U). It is an executable file (EXE file) works with Oculus Rift on Windows 10.

The IVR was intended to be a behavioral analysis tool instead of a training tool; hence, it allowed participants to choose their behavior and did not instruct them on the best evacuation practice. However, a few instructions and restrictions were provided in the IVR to drive the narrative (Feng et al., 2018b). Participants were not able to explore the areas of the virtual building that was not included in the storyline of the IVR. In this way, they were encouraged to complete the IVR by following a predefined storyline. The storyline consisted of the following points, as shown in Fig. 2:

1. Participants start the IVR by standing outside the hospital.

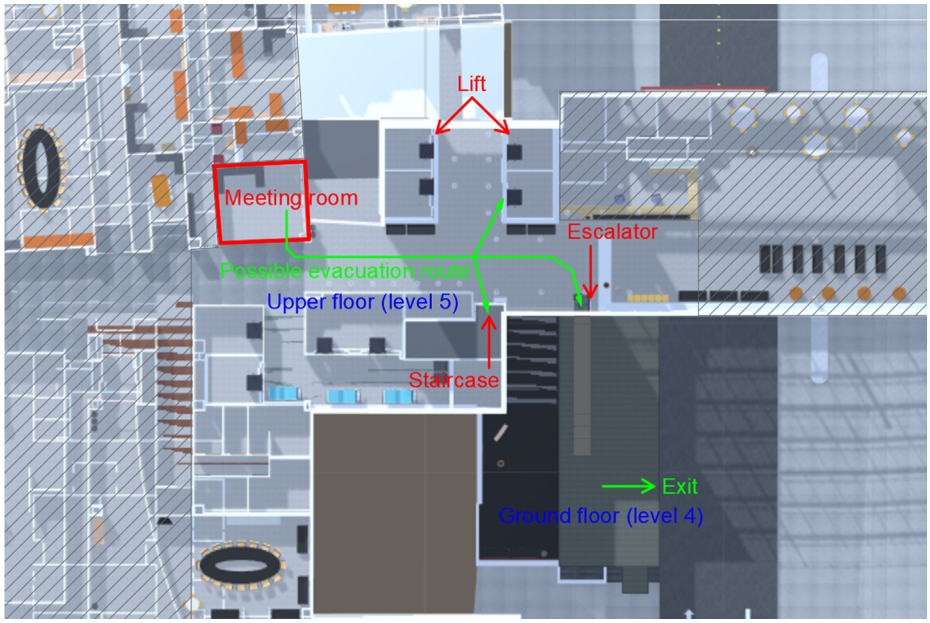

Fig. 1. The floor plan of the virtual environment (the hatched area is restricted for movement after an earthquake by debris blocking the ways).

2. Participants are guided to reach a meeting room in the hospital and welcomed by one doctor NPC and one visitor NPC in the room.
3. An earthquake strikes the hospital, which lasts for 60 s.
4. Both NPCs drop, cover and hold.
5. Objects start falling down from the table and shelves, glass panels start breaking down, ceiling tiles start falling down, a photocopier starts emitting electric sparks.
6. The door of the meeting room is locked so participants cannot leave the room, and they can decide to stand or crouch in any place of the room (including beside the table).
7. Once the shaking stops, the doctor NPC tells participants to wait for further instructions while the doctor NPC leaves the room to assess the situation outside. The visitor NPC is terrified and trembling inside the room.
8. Participants can choose to stay in the meeting room or start evacuating without waiting for the doctor NPC.
9. Participants make their way through a corridor and descend to the ground floor by using a staircase or an escalator. In the same scenario, a number of NPCs start evacuation while participants are walking in the corridor.
10. Participants exit the building and reach an assembly area. A number of NPCs are grouped in three different locations outside the building.

2.2. Apparatus

The experiment was carried out in a meeting room at Auckland City Hospital. The IVR was directly run in Unity that was deployed on a PC workstation equipped with a 2.4 GHz Intel Xeon E5-2640 processor, 64 GB RAM, and two Nvidia Quadro M5000 graphics cards. The IVR headset was an Oculus Rift (www.oculus.com). The remote controller was an Oculus Remote. The graphics output of the HMD was also transmitted to an LED screen, which allowed researchers to observe participants' behavior as it was performed in the IVR. Additionally, a chair-shaking system was implemented to provide a physical shaking dimension by vibrating the moving base platform on which the participants were sitting during the virtual earthquake. In this way, participants could feel physical vibration while the earthquake struck in the IVR simultaneously. The VPA recording device was the microphone built in the Oculus Rift. Fig. 3 shows the setup of the apparatus.

2.3. Participants

A total of 87 participants (42 females, 45 males) were recruited through notices posted on the intranet of Auckland District Health Board staff newsletters, and posters and leaflets posted in Auckland City Hospital and the University of Auckland. Participants were informed by Participation Information Sheet that the experiment involved visual simulations using IVR, in which case normal vision is essential (it is possible to use personal glasses). Four out of 87 participants had to quit the experiment due to motion sickness caused by the IVR experience. The remaining 83 participants included 29 staff members of the hospital and 54 visitors. Participant ages ranged from under 20 to over 70, with 60 percent of them between 20 and 39. Full demographics are shown in Table 1. The frequency of participant experience of fire drills and earthquake drills were collected, as shown in Table 2. The results revealed that participants lacked training and practice in earthquake drills in comparison with fire drills. Participants were asked to self-rate their awareness and preparedness of the proper behavioral responses required in earthquake emergencies on a 7-point Likert scale (-3 = unprepared, $+3$ = prepared). The results are reported as boxplots (Staff: M = 0.79, SD = 1.45; Visitors: M = 0.44, SD = 1.77), as shown in Fig. 4. No significant difference was reported by Wilcoxon Signed Ranks tests. Participants were also asked to state whether they had experienced IVR (e.g., games, videos, tours, or demos) before, as shown in Table 3. A Kruskal-Wallis test confirmed no significant difference among the groups.

2.4. Procedure

The experiment was conducted between July and August 2017. Ethical clearance was granted from The University of Auckland Human Participants Ethics Committee, and Institutional Approval was granted from the Auckland District Health Board Research Review Committee. Before the experiment, participants received the Participation Information Sheet, which informed them that the purpose of this experiment was to study human behavior in earthquakes using IVR technology. Then they gave their consent for participation and collecting experiment data by the researchers, which included questionnaires, and audio and video recordings. Participants were also informed that they could withdraw the experiment at any time without providing any reason.

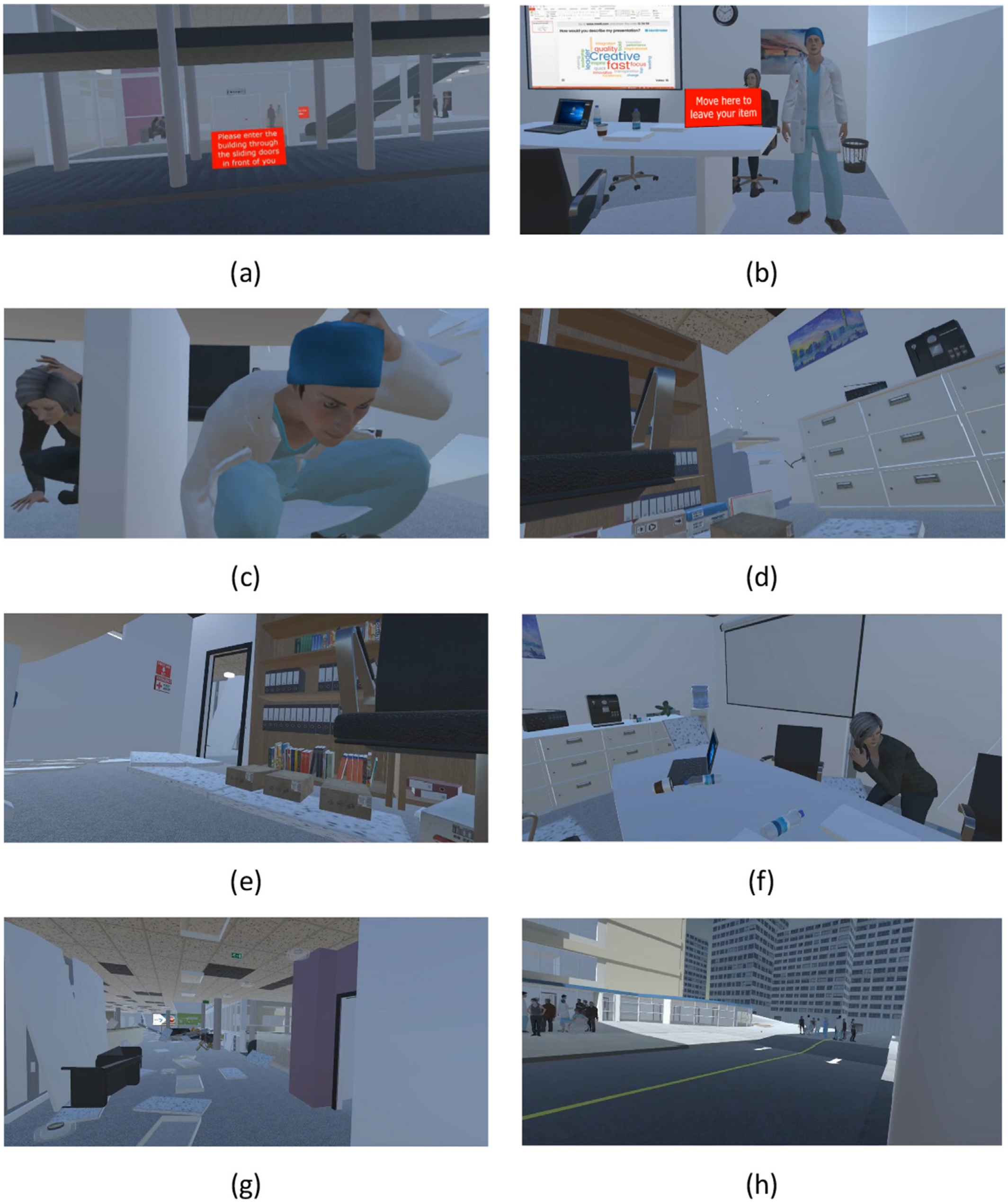

Fig. 2. The storyline of the IVR: (a) Before the earthquake, outside the hospital building; (b) Before the earthquake, inside the meeting room; (c) During the earthquake, inside the meeting room, NPCs are under a table; (d) During the earthquake, inside the meeting room, a photocopier starts emitting electric sparks; (e) During the earthquake, inside the meeting room, objects start falling; (f) After the earthquake, inside the meeting room; (g) After the earthquake, outside the meeting room; (h) After the earthquake, outside the hospital building.

After completing the consent forms, participants were given instructions about how to use IVR headsets and remote controllers as well as health and safety induction about experiencing IVR. Then participants were given brief instructions about VPA. Further detailed instructions were given in a tutorial session later in the IVR. Participants were invited to sit in a swivel chair, which was mounted on the chair-shaking system for the entire IVR session. Participants were assisted in putting on an HMD and adjusting it, so they had a clear view and were comfortable. Before the start of the actual simulation, participants were led through a tutorial session in which they practiced walking, turning, crouching and interacting with objects in order to habituate themselves to IVR environment and navigation controls. Additionally, participants were asked to perform VPA while they were interacting in the tutorial. VPA was explained and demonstrated using examples of decision-making processes in the tutorial until participants understood and felt comfortable with the procedure. They were asked to focus on verbalizing why they did the actions they chose to do, not just describing what they were doing. After participants indicated they felt sufficiently familiar with IVR environment and VPA, the simulation was started.

Participants were instructed to begin their VPA once they entered the meeting room in the IVR, where an earthquake struck shortly upon arrival. VPA was continued until the IVR was ended. Once participants began, researchers did not interface or ask questions during the process, other than to gently remind them to "Please remember to speak your thoughts aloud," or similar, if they had not spoken for 10–20 s. The verbal protocols of participants were recorded using the microphone built in Oculus Rift and synchronized with their IVR experience so that both audio and video could be played back in one file as in MP4 format.

Fig. 3. Experiment apparatus setup (Lovreglio et al., 2018).

Table 1
The demographics of the participants.

	N	%	N	%
	Staff (N = 29)		Visitor (N = 54)	
Sex				
Female	19	65.5%	19	35.2%
Male	10	34.5%	35	64.8%
Age				
< 20	0	0.0%	2	3.7%
20–29	4	13.8%	21	38.9%
30–39	5	17.2%	20	37.0%
40–49	8	27.6%	5	9.3%
50–59	8	27.6%	3	5.6%
60–69	4	13.8%	2	3.7%
70–79	0	0.0%	1	1.9%
Occupation (staff only)				
Medical staff	9	31.0%		
Admin staff	19	65.5%		
Years in the hospital (staff only)				
1–5	14	48.3%		
6–10	7	24.1%		
11–15	6	20.7%		
16–20	1	3.4%		
> 20	1	3.4%		

Table 2
Participant experience of fire and earthquake drills.

Frequency	Staff				Visitors			
	Fire		Earthquake		Fire		Earthquake	
Never	10	(34.5%)	24	(82.8%)	11	(20.4%)	45	(83.3%)
Once a year	7	(24.1%)	3	(10.3%)	20	(37.4%)	4	(7.4%)
Twice a year	5	(17.2%)	1	(3.4%)	14	(25.9%)	1	(1.9%)
More than twice a year	6	(20.7%)	0	(0.0%)	4	(7.4%)	0	(0.0%)
Unsure	1	(3.4%)	1	(3.4%)	5	(9.3%)	4	(7.4%)
Other	0	(0.0%)	0	(0.0%)	0	(0.0%)	0	(0.0%)
TOTAL	29		29		54		54	

2.5. Measures

The audio and video recording file of each participant was replayed after the experiment. An initial coding scheme was developed to transcribe and code key factors. The coding was carried out across five sections of the IVR, representing five key decision points:

In the meeting room, during the earthquake
In the meeting room, after the earthquake
Immediately outside the meeting room (in the corridor)
Staircase/escalator
Outside the hospital building

This coding scheme included all the information pertaining to factors driving participants' decisions and actions, and factors relating to information-seeking. Two researchers independently coded key factors. The two initial codes were cross-checked and merged into one final code (i.e., a transcript) for each participant based on mutual agreement. Then, the researchers undertook thematic analysis to locate common patterns between different transcripts (Braun and Clarke, 2006). According to thematic analysis, the transcripts were scrutinized, and common factors were grouped together to identify a list of key factors (Dey, 2003). Table 4 illustrates an example of a thematic analysis of the current study. This list of factors was updated iteratively as the analysis progressed until a final list of key factors influencing earthquake evacuation decisions was determined. This process was carried out separately for participants identified as visitors and staff members.

3. Results

3.1. Themes by IVR sections

The key decision-making and information-seeking themes were identified in each section of the IVR, as shown in Tables 5 and 6. Multiple themes could be recognized from one participant in each section. Staff and visitor data have been analyzed separately. A Chi-square test of independence was performed to test the significance of the difference between two groups: staff and visitors. Where the assumption of Chi-square test (at least 80% of the cells have expected count larger than 5) was violated, a Fisher's exact test of independence was performed to assess the significance of differences. The results of significance tests are reported in Tables 5 and 6. Five significant differences were identified between staff and visitors (i.e., p-value < 0.05) indicating that staff and visitors showed different behavior. These differences are discussed in the following sections:

1. Move other objects away while crouching (see Table 5, section 1). Staff were more concerned about the hazards around while they were crouching under a table.
2. Damage and hazards (see Table 6, section 4). Staff were keener on assessing the damage around.
3. Location (see Table 6, section 4). Visitors focused more on exit signs.
4. Familiarity (see Table 6, section 4). Staff focused more on the pathway they used before to reach the meeting room.
5. Stay with other people (Table 5, section 5). Visitors were more willing to be accompanied by others.

The detailed results of each section are reported in Appendix A.

3.1.1. Move other objects away while crouching

While the earthquake was taking place, most of the participants decided to crouch under a table. The overwhelming driver behind this behavior was the desire to be protected (especially their heads) from falling objects. While crouching, staff were more concerned about the surroundings then visitors, manifesting in they tended to push the chair away to make more safe space. This behavior was driven by the desire

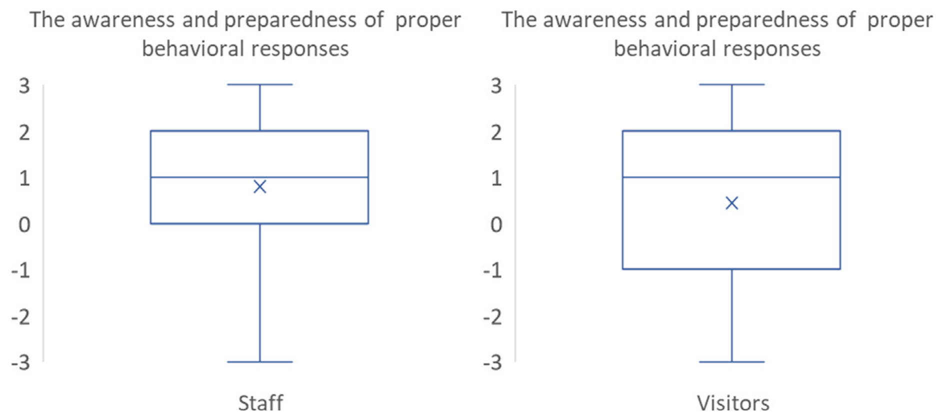

Fig. 4. Self-rated awareness and preparedness of the proper behavioral responses required in earthquake emergencies.

Table 3
Experience with IVR.

Experience	Staff		Visitors	
No	18	(62.1%)	28	(51.9%)
Yes	11	(37.9%)	25	(46.3%)
Unsure	0	(0.0%)	1	(1.9%)
TOTAL	29		54	

to be protected from the moving objects around them.

3.1.2. Damage and hazards

While evacuating in the corridor after the earthquake, staff paid more attention to the damage and hazards around than visitors. The concern about safety while evacuating appeared to drive this information-seeking behavior. This driver continued from the previous scenario, where staff tended to make more safe space during the earthquake. The alert of safety might come from the professionalism of staff as medical personnel.

3.1.3. Location

Before participants descended to the ground floor using either a staircase or a stationary escalator, visitors sought location information to a greater extent than staff. Specifically, they were looking for exit signs. Mostly because staff were already familiar with the locations of stairs and exits. Both staff and visitors were still concerned about their safety at this point, given that they checked the conditions of the escalator and staircase before and while using them.

3.1.4. Familiarity

Before deciding a way to exit, staff were more actively thinking about which way they came before. None of the visitors sought for this information. Visitors tended to follow others (other NPCs) and look for exit signs. Staff were more familiar with the layout of the hospital building; in which case they might configure an alternative evacuation route that could be safer and faster.

3.1.5. Stay with other people

At the end of evacuation, participants were gathering in an assembly area outside the hospital building. A significant between-group difference is that visitors were more willing to stay with others than staff. One possible explanation is that visitors were less familiar with the assembly area, and they would like to join the groups where others were staying. As well as this, visitors were also seeking information and instructions from others, especially authority figures, given that they were trying to investigate what was going on and what should they do after joining others in the assembly area.

3.2. Comparisons with existing literature

In Section 1, we have identified several studies in which behavioral data were collected using video analysis of CCTV videos or videos available on social media. In this section, we compare the decision-making data obtained using the VPA with the latest data published by Bernardini et al. (2019) regarding the New Zealand case studies. This was done by comparing the themes presented in Table 5 with the data available in Bernardini et al. (2019). The comparison between real-life observations and IVR-based observations is not straightforward as it is apparent from Table 7. For instance, out of the seventeen actions compared, only six are somehow comparable in term of percentages such as “Check other people (evacuation stages 2 and 3)”, “Use phones/radios for information/support”, “Following other people (evacuation stages 3 and 4)“ and “Stay with other people”, which allows some levels of valid comparison over a small number of actions and provides some credibility to the VPA analysis undertook in the IVR environment over real-life scenarios. There are also significant differences in some actions such as “Take cover (under a table or doorway, at a corner)”, “Check other people (evacuation stage 1), and “Notice hazards (falling/damaged objects) and mitigate or keep away from them while evacuating”. This may result from the difference between occupant samples as our samples are mainly hospital occupants. But the most important aspect is that VPA and IVR provide a richer characterization of actions than what real-life observations can provide (see the “NAs” in Table 7). This opens up new avenues of opportunities for the use of IVR and other methods to capture behavioral data during earthquake emergencies such as VPA.

Table 4
An example of thematic analysis.

Participants	Transcripts (for decision point 1)	Key factors
a	Crouch on the floor. Move the chair to clear more space.	1. Take cover (get protection from falling objects)
b	Crouch so that things do not fall on top of her. Talk to others asking if they are ok and tell them to stay under the table.	2. Move other objects away (get more safe space) 3. Check other people (concern for their conditions)
c	Get under the table immediately. Push the chair away.	

Table 5
Decision-making themes.

Sections	Actions	Staff N = 29	%	Visitors N = 54	%	Significance Test
1. In the meeting room, during the earthquake	Take cover (under a table or doorway, at a corner)	28	96.6%	50	92.6%	$\chi^2(1, N = 83) = 0.522, p = 0.470$
	Move other objects away while crouching	10	34.5%	5	9.3%	$p = 0.007$ *
	Check other people	7	24.1%	8	14.8%	$\chi^2(1, N = 83) = 1.108, p = 0.293$
	No idea what to do	0	0.0%	4	7.4%	$p = 0.167$
2. In the meeting room, after the earthquake	Notice hazards (falling/damaged objects) and mitigate or keep away from them	19	65.5%	26	48.1%	$\chi^2(1, N = 83) = 2.293, p = 0.130$
	Notice instructions and decide to follow them (stay in the room until it is safe to evacuate)	17	58.6%	20	37.0%	$\chi^2(1, N = 83) = 3.558, p = 0.059$
	Check other people	18	62.1%	25	46.3%	$\chi^2(1, N = 83) = 1.880, p = 0.170$
	Use phones/radios for information/support	8	27.6%	7	13.0%	$\chi^2(1, N = 83) = 2.725, p = 0.099$
	Start evacuating without following instructions	1	3.4%	10	18.5%	$p = 0.087$
	Take first aid kit	2	6.9%	4	7.4%	$p = 1.000$
3. Immediately outside the meeting room (in the corridor)	Following other people	14	48.3%	24	44.4%	$\chi^2(1, N = 83) = 0.112, p = 0.738$
	Notice hazards (falling/damaged objects) and mitigate or keep away from them	6	20.7%	7	13.0%	$p = 0.362$
	Check other people	4	13.8%	13	24.1%	$\chi^2(1, N = 83) = 1.224, p = 0.268$
4. Staircase/escalator	Following other people	8	27.6%	11	20.4%	$\chi^2(1, N = 83) = 0.557, p = 0.456$
	Check stairs/escalator	8	27.6%	9	16.7%	$\chi^2(1, N = 83) = 1.381, p = 0.240$
5. Outside the hospital building	Go to an assembly area/open space	12	41.4%	27	50.0%	$\chi^2(1, N = 83) = 0.563, p = 0.453$
	Stay with other people	4	13.8%	19	35.2%	$\chi^2(1, N = 83) = 4.310, p = 0.038$ *

* $p < 0.05$, the difference is statistically significant.

4. Discussion

Decision-making and information-seeking themes were identified as the result of VPA. This method uncovers the reasoning and motivation behind participants' behavioral responses to earthquakes and post-earthquake evacuation. These unique insights are critical for successful behavior change and improved safety. Participant behavior was driven by the desire to protect themselves, environmental cues, messages from trusted individuals, and the cues from other people around them. This finding supports the Protective Action Decision Model which posits that individuals take cues from both physical and social environment to make decisions and take actions in response to hazards and disasters (Lindell and Perry, 2012; Perry et al., 2001). Beyond that, the results also reveal three higher-level themes that will be important to consider when designing both earthquake evacuation training and evacuation procedures.

First, humans are social animals. These results highlight people's natural tendency to take cues from the behavior of others. People's decision-making tended to be driven, at least in part, by what those around them were doing in the greatest numbers (Nilsson and Johansson, 2009). Most participants took cues to the direction they should exit by looking for other people, and many chose to join the largest group of people outside the hospital building, stating this to be the case. This is consistent with the suggestion that social influence affects evacuation route choice (Kinateder et al., 2014b). Participants tended to feel comfortable if they were accompanied by other people when dealing with such emergencies. Participants also showed a high level of concern for the wellbeing of the other visitor NPC in the meeting room with them, consoling the visitor NPC, talking to the visitor NPC and advising the visitor NPC to follow their lead (e.g., to stay under a table, or to exit the building). This was true for both visitors and staff, so it cannot simply be the product of a duty of care obligation on hospital staff. Moussaïd and Trauernicht (2016) claimed a similar finding in their study that participants took the same risk to help others in both emergencies and normal conditions. Future training and guidelines need to consider this natural inclination of people and investigate ways to make the most of this human-centricity.

Second, and related to the above, participant behavior was particularly influenced by those who appeared to be in authority positions (in our case, the doctor NPC), which has been observed in real-life evacuation cases (Donald and Canter, 1992; Gill et al., 2011; Johnson et al., 1994). This phenomenon is well documented in psychological literature. Bushman (1988) examined the effect of uniforms on compliance with authority, particularly in relation to female authority figures, with the use of uniforms resulting in an increase in participant compliance. In a review of literature on source credibility, Pornpitakpan (2004) found that messages from higher credibility sources generally change both attitudes and behavior more reliably than lower credibility sources. In our study, it appears that those who followed authority figures tended to hand over much of their own decision-making autonomy. For instance, when following the doctor NPC, they appeared to focus less on assessing the damage around them or checking the integrity of their escape route. This phenomenon is common in fire emergencies that can be explained by the role-rule model (Fridolf et al., 2013; Tong and Canter, 1985). This model describes that people's behavior is affected by their roles. Having uniforms or other identifying features that imply a level of authority for those leading evacuation is likely to assist in getting others to follow instructions; however, this may also result in a sacrifice of situational awareness and autonomy by those following. This trade-off could be investigated further in order to establish the ideal balance in leadership style for earthquake evacuation.

Third, there appeared to be two types of participants: Flight - those who wanted to exit the building immediately and did not seem influenced by the doctor NPC telling them to wait (and in many cases, did not mention it at all); and Wait - those who waited for the doctor NPC to

Table 6
Information-seeking themes.

Sections	Information	Staff N = 29	%	Visitors N = 54	%	Significance Test
1. In the meeting room, during the earthquake	Damage and hazards - What and how much is falling down/being damaged?	11	37.9%	19	35.2%	$\chi^2(1, N = 83) = 0.062, p = 0.804$
	Other people - Where are other people? What are they doing?	7	24.1%	8	14.8%	$\chi^2(1, N = 83) = 1.108, p = 0.293$
	Protection - How strong is the shelter (table)?	0	0.0%	3	5.6%	$p = 0.548$
2. In the meeting room, after the earthquake	Damage and hazards - What and how much is falling down/being damaged?	23	79.3%	33	61.1%	$\chi^2(1, N = 83) = 2.847, p = 0.092$
	Useful items - What in the room could be useful?	6	20.7%	4	7.4%	$p = 0.090$
	Other people - Are other people hurt or in need of assistance?	18	62.1%	25	46.3%	$\chi^2(1, N = 83) = 1.880, p = 0.170$
	Further instructions and assistance - Is there anyone coming to help?	1	3.4%	4	7.4%	$p = 0.653$
	Aftershock - Are there any signs of aftershocks?	0	0.0%	4	7.4%	$p = 0.292$
3. Immediately outside the meeting room (in the corridor)	Damage and hazards - What and how much is falling down/being damaged?	14	48.3%	7	13.0%	$\chi^2(1, N = 83) = 12.449, p < 0.001$ *
	Other people - Where are other people? What are they doing? Where are they going? What conditions are they in?	8	27.6%	10	18.5%	$\chi^2(1, N = 83) = 0.913, p = 0.339$
	Location - Where are the evacuation routes and exit signs? Where are the signs indicating the stairs and which floor am I on?	1	3.4%	9	16.7%	$p = 0.154$
	Familiarity - Which way did I come from?	0	0.0%	2	3.7%	$p = 0.540$
4. Staircase/ escalator	Safety and usability - Are the stairs/escalator in good condition/being blocked? Are there any falling/collapse risks?	8	27.6%	9	16.7%	$\chi^2(1, N = 83) = 1.381, p = 0.240$
	Other people - Where are other people? What are they doing? Where are they going? What conditions are they in?	4	13.8%	5	9.3%	$p = 0.713$
	Location - Where are the evacuation routes and exit signs? Where are the signs indicating the stairs and which floor am I on?	0	0.0%	9	16.7%	$p = 0.024$ *
	Familiarity - Which way did I come from?	3	10.3%	0	0.0%	$p = 0.040$ *
5. Outside the hospital building	Other people - Where are other people gathering? What conditions are they in?	8	27.6%	10	18.5%	$\chi^2(1, N = 83) = 0.913, p = 0.339$
	Buildings - How far away are other buildings?	4	13.8%	13	24.1%	$\chi^2(1, N = 83) = 1.224, p = 0.268$
	Assembly area - Where is the assembly point? Is there anything indicating it?	5	17.2%	8	14.8%	$p = 0.761$
	Further instructions and assistance - Is there anyone coming to help?	0	0.0%	2	3.7%	$p = 0.540$

* $p < 0.05$, the difference is statistically significant.

Table 7
Data comparisons.

Evacuation Stage	Actions	Present study	Bernardini et al. 2019
1. In the meeting room, during the earthquake	Take cover (under a table or doorway, at a corner)	94%	13%
	Move other objects away while crouching	18%	NA
	Check other people	18%	38%
	No idea what to do	5%	NA
2. In the meeting room, after the earthquake	Notice hazards (falling/damaged objects) and mitigate or keep away from them	54%	NA
	Notice instructions and decide to follow them (stay in the room until it is safe to evacuate)	45%	NA
	Check other people	52%	38%
	Use phones/radios for information/support	18%	23%
	Start evacuating without following instructions	13%	NA
	Take first aid kit	7%	NA
3. Immediately outside the meeting room (in the corridor)	Following other people	46%	35%*
	Notice hazards (falling/damaged objects) and mitigate or keep away from them while evacuating	16%	71%**
	Check other people	20%	31%***
4. Staircase/escalator	Following other people	23%	35%*
	Check stairs/escalator	20%	NA
5. Outside the hospital building	Go to an assembly area/open space	47%	NA
	Stay with other people	28%	35%

NA: Not Applicable.
* The original paper phrase it as “herding behavior”.
** The original paper phrase it as “Debris avoidance” and refers only to outdoor.
*** The original paper phrase it as “Information exchange”.

come back because they were told to (this relates to the trust in authority discussed above). There were very few participants who waited for a long time but decided to leave before the doctor NPC returned. The recommended advice to improve safety during and immediately after an earthquake is to shelter in place, so it will be necessary to establish methods for overcoming the natural flight response. About 13% of participants in this study immediately evacuated after the shaking stopped, with most of them stating they felt unsafe where they were. This is similar to the findings from a recent earthquake in a New Zealand population (Christchurch 2011 earthquake) where 10.5% of people responded that they evacuated immediately, and those that evacuated were more likely to report a higher level of fear from the earthquake (Lindell et al., 2016). Minimizing the flight response can most likely be achieved through improved preparedness and training, good leadership from trusted individuals who know the correct behavior, and an improved understanding of the relative safety of the environment and building integrity.

4.1. Implications

The results of the VPA analysis also have immediate implications for current guidelines, training, education, and practice. First, there is a residual belief that doorways remain a potential safe place during an earthquake. While almost all participants got under a table in this study, which is the correct behavior (Mahdavifar et al., 2009), some debated whether they should be in a doorway or should move to it halfway through the shaking. Likewise, on exiting the building, one participant chose to stand in the building's main entrance because “that is what I was taught” rather than proceeding to an assembly area. This propensity to view doorways as the safest location is likely to be reduced as the younger generation come through; however, for people beyond the millennial generation, there may still be a benefit in a focused attempt to allay the myth that doorways can provide protection. Apart from doorways, few participants tried to escape from the meeting room immediately or had no idea what to do when the earthquake struck. This implies that messaging about what to do in an earthquake, whatever the source, has had some degree of penetration within the population.

Second, the participants in this study seemed to have a good understanding on the need to drop and cover, but the ‘hold’ element of ‘Drop, cover, hold’ did not seem to have been absorbed to a level where it was put into practice (at least in the simulation). There could be some benefit in a campaign focusing on this element. For example, addressing the questions: What do I hold on to? How can I do that in an earthquake? What would that look like? And importantly, why do I need to do that?

Finally, following the earthquake, nearly all the participants tried in some ways to assess the integrity of the building and determine how safe it was for them to stay inside it. While most decided one way or another based on the damage they could see, some admitted that while that was what they were trying to do, they really had no idea what they should be looking for. Acknowledging that these could never be foolproof, developing and advertising simple guidelines on what to look for to help determine structural integrity could assist with decision-making processes, as could sharing the relative safety inside buildings that meet current standards, to encourage people to be more confident and informed in their decision to stay in place.

4.2. Limitations

This study also has limitations. First, we need to acknowledge that the gap between IVR and reality still exists. One of the issues is motion controls. There were cases where participants forgot how to control themselves in the IVR, especially when they were facing intense events such as the earthquake strike (e.g., “I want to crouch under the table, how can I do that?”). This might lead to distractions on giving verbal thoughts timely while making decisions. Another issue is the fidelity of the IVR. Although this IVR has been reported with a high level of realism, which was identified as the main contributor to the sense of presence (Lovreglio et al., 2018), there are still spaces for improvement. The NPCs of the IVR were controlled by predefined scripts; hence, they were not able to respond to participants. Participants were also not able to interact with other objects in the IVR. As such, the behavior and thoughts of participants might be affected by the absence of response and feedback to their actions (Bahrami et al., 2012). These limitations were related to the ecological validity of IVR, as discussed in Section 1. The ecological validity of our simulation is considered less than real-world cases. Being one of the laboratory experiments, the loss of ecological validity is inherent as laboratory experiments are the abstractions of reality (Loomis et al., 1999).

Second, participants might show more pro-social behavior than they would in reality (Kuusela and Pallab, 2000). While participants were conducting VPA in the IVR, they were aware of the observation from researchers. Previous studies have pointed out that the awareness of observation from others may lead to normative or socially desirable behavior, which is known as the watching eyes phenomenon (Leary and Kowalski, 1990; Pfattheicher and Keller, 2015; Risko and Kingstone, 2011; van Rompay, Vonk, Fransen, 2009).

4.3. Future research

Future research can extend the external validity of the present study by focusing on other buildings and countries. Different building occupants (or even outdoor scenarios) in different countries should be investigated. As well as this, future research can be taken to reduce the gap between IVR and reality. The motion controls and fidelity of IVR can be improved to facilitate a more credible testing environment, offering more ecological validity. A more natural way of interaction and navigation can be considered.

In our study, the doctor NPC was programmed to execute sensible actions. Most of the participants perceived the doctor NPC as an authority figure and followed their actions and instructions. It would be interesting to investigate the decision-making processes when people receive conflicting information, especially when it is from an authority figure, such as how participants would have behaved if the doctor NPC had not done something sensible. In related works, Kinateder et al. (2014b) found that social influence plays an important role in disturbing evacuation route choice. Additionally, the doctor NPC has a male appearance, and the visitor NPC has a female appearance. Another interesting research topic would be whether current social expectations of the roles of people affect evacuation decisions and behavior.

Regarding earthquake safety, further work could be done to reduce any unsafe flight response behavior in earthquake evacuation. Finally, finding the right balance between following authoritative leaders while maintaining a level of autonomy and risk awareness could be further examined.

5. Conclusions

This study aims to investigate the decision-making processes of building occupants during earthquakes and post-earthquake evacuation. Participants were exposed to an earthquake and performed post-earthquake evacuation in an IVR. VPA was applied as a cognitive analysis tool to track participants' thoughts and intent while performing tasks. Factors relating to decision-making and information-seeking were coded and analyzed.

Results reveal that the majority of participants took cues from the behavior of other people while making decisions and were driven to find and be accompanied by other people when facing such emergencies. This extended to a concern about the wellbeing of other people around. Results also imply that evacuation decisions are likely to be influenced by authority figures. Participants were willing to hand over their decision-making autonomy to someone else in authority positions. However, in contrast, 13% of participants showed the flight response, a common instinct when facing danger. They tended to move out of the building without paying attention to the other people around them or follow the instructions from authority figures. These findings indicate the need for improved training, the importance of leadership, and the need for better information transfer about visual building damage and actual safety.

From a methodological point of view, this study attempts to cast light on the combination of VPA and IVR. It is impossible to collect stated preference data concurrently in actual emergencies, and the stated and revealed preference data collected retrospectively can be suffered from bias. For instance, it is difficult to understand if building occupants were looking at exit signs or if they were assessing damages while evacuating through video analysis. The combination of VPA and IVR provides an alternative way to uncover decision-making processes for evacuation studies.

Acknowledgements

This research has been funded by the MBIE-Natural Hazards Research Platform (New Zealand), Grant Number: C05X0907.

Appendix A

The detailed results of decision-making and information-seeking themes by IVR sections.

1 In the meeting room, during the earthquake

The first section of the IVR analyzed was the time during which participants were in the meeting room, and the earthquake was taking place. During this period, the overwhelming driver behind participants' behavior was the desire to be protected (especially their heads) from falling or moving objects. This desire extended to the desire for others to be protected too, manifesting in participants not only getting under a table themselves but also encouraging other NPCs in the room to do so. There was a little uncertainty voiced by the visitors as to what exactly they should do when the shaking started, but almost all participants eventually crouched under a table.

In terms of the information participants were seeking, the main themes were around the kinds of damage to the room and building being caused by the earthquake, manifesting in actively looking for what was falling down and where and what hazards were being created, and the capacity of the table and other aspects of the room to protect them and others from harm. Staff focused slightly more on information regarding the safety of others, while visitors focused slightly more on the protective properties provided by the room and furniture.

2 In the meeting room, after the earthquake

In the meeting room following the cessation of the earthquake, participant decisions were mainly driven by the potential for them to be injured in further aftershocks or by the objects already damaged during the earthquake, such as falling ceiling tiles, unsteady furniture and partition walls, and a damaged photocopier with electric sparks. This drove participants to stay under the table or to unplug the photocopier or stay far away from it.

Participants were also driven by the desire to follow the instructions of someone who seemed to be an authority figure (the doctor NPC in the meeting room) and the example of others in general. This drove them to wait in the room until the doctor NPC returned for them and to want to leave when the visitor NPC started to leave. However, a few participants decided to start evacuating without following instructions or the example of others. This decision was mainly driven by the potential for them to be injured by the risky environment around them. Participants felt uncomfortable and unsafe staying in the meeting room after assessing the damage around them, especially when they had noticed the photocopier might catch fire. Another driving factor was the desire to report and find out more about the incident, given that a few participants decided to use a cellphone or radio for getting more information or support. Participants were also concerned about the wellbeing of other people, manifesting in participants trying to comfort and help the visitor NPC in the meeting room, and taking first aid kit with them in case someone else might need it.

Unsurprisingly, the main information-seeking themes focused around ascertaining the level of damage to the meeting room and building, along with the information on the status of others in the vicinity. This led to the decision to look for useful items and figure out how to mitigate the hazards posed. Beyond that, participants were also concerned about aftershocks so that they paid attention to the signs of aftershocks. A few participants were also looking or waiting for further instructions and assistance, manifesting in participants wondering if anyone was coming to the meeting room to help them or give instructions.

3 Immediately outside the meeting room (in the corridor)

In the third section of the IVR, participants left the meeting room and made their way through the corridor towards the hospital reception on the same floor. During this section, participant actions were mainly driven by doing what others were doing. In most cases, this involved following the doctor NPC or the visitor NPC towards the stairs. In these cases, participants tended to focus on the doctor NPC and the visitor NPC, rather than making assessments of the situation themselves. In other cases, such as when participants left before the doctor NPC returned, participants still looked to others around to see which way they were exiting. In these cases, decision-making was also driven by the perceived safety of the direction and route out and the location of others who may need assistance. Participants were still concerned about their own safety as well as others. This drove them to check surroundings and the conditions of others while walking in the corridor.

Participants were generally seeking information on the location and behavior of others (especially those nearest them), the damage to the building, and the hazards posed by the building. Participants noted that while they were trying to assess damage, they did not always know what they should be looking for in order to do so. Visitors also sought location information, such as determining where they were, what floor they were on, and which way they came from. Staff did not appear to need this confirmation.

4 Staircase/escalator

In the next section of the IVR, participants descended to the ground floor using either a staircase or a stationary escalator. Once again, the main theme driving participant actions and decisions was the desire to stay with the people they were following. Where participants were not following others, they were concerned about getting out using a fast and safe way. Many articulated that they should not use lifts. Familiarity and speed appeared to drive the decision to use an escalator, while the emergency exit signs appeared to drive the decision to use a staircase. In both ways, participants were still concerned about their safety; therefore, they checked the conditions of the escalator and staircase before and while using them.

Once again, visitors sought location information to a greater extent than staff, mostly because staff were already familiar with the locations of stairs and exits.

5 Outside the hospital building

Finally, participants made their way to the outside of the hospital building where they were told they should move to an assembly area. The participant actions were driven by two main concerns: First, being in an open space away from other buildings; and second, being where others were located and gathered. A number of participants were concerned particularly about being in the right place at the assembly point. As participants did not know the correct location of the assembly point, their guesses were based on the former two drivers.

Understandably, the main information participants were seeking was the guidance on the location of the assembly area (e.g., signage and authority figures); and in the absence of this, they were considering the distance to surrounding buildings and the location of others. Many participants assumed that the assembly area would be at the place where most people were standing. Participants were also expecting further information and instructions from others, especially authority figures, given that they were trying to investigate what was going on and what should they do after joining others in the assembly area.

References

Aarts, H., Verplanken, B., van Knippenberg, A., 1998. Predicting behavior from actions in the past: Repeated decision making or a matter of habit? J. Appl. Soc. Psychol. 28 (15), 1355–1374.

Arias, S., La Mendola, S., Wahlqvist, J., Rios, O., Nilsson, D., Ronchi, E., 2019. Virtual reality evacuation experiments on way-finding systems for the future circular collider. Fire Technol. 1–22.

Arias, S., Ronchi, E., Wahlqvist, J., Eriksson, J., Nilsson, D., 2018. ForensicVR: Investigating human behaviour in fire with Virtual Reality. Lund University 3218.

Arnold, C., Eisner, R., Durkin, M., Whitaker, D., 1982. Occupant behavior in a six-storey office building following severe earthquake damage. Disasters 6 (3), 207–214.

Austin, J., Delaney, P.F., 1998. Protocol analysis as a tool for behavior analysis. Anal. Verbal Behav. 15 (1), 41–56.

Averill, J.D., Kuligowski, E.D., Peacock, R.D., 2011. After the alarm sounds: historical, present and future perspectives. Fire Protection Engineering.

Bahrami, B., Olsen, K., Bang, D., Roepstorff, A., Rees, G., Frith, C., 2012. Together, slowly but surely: The role of social interaction and feedback on the build-up of benefit in collective decision-making. J. Exp. Psychol. Hum. Percept. Perform. 38 (1), 3.

Banks, V.A., Stanton, N.A., Harvey, C., 2014. What the drivers do and do not tell you: using verbal protocol analysis to investigate driver behaviour in emergency situations. Ergonomics 57 (3), 332–342.

Barber, A.E., Roehling, M.V., 1993. Job postings and the decision to interview: A verbal protocol analysis. J. Appl. Psychol. 78 (5), 845.

Berlin, J.M., Carlström, E.D., 2015. Collaboration exercises: what do they contribute? –a study of learning and usefulness. J. Contingencies Crisis Manage. 23 (1), 11–23.

Bernardini, G., Lovreglio, R., Quagliarini, E., 2019. Proposing behavior-oriented strategies for earthquake emergency evacuation: A behavioral data analysis from New Zealand, Italy and Japan. Saf. Sci. 116, 295–309.

Bernardini, G., Quagliarini, E., D'Orazio, M., 2016. Towards creating a combined database for earthquake pedestrians' evacuation models. Saf. Sci. 82, 77–94.

Bettman, J.R., Park, C.W., 1980. Effects of prior knowledge and experience and phase of the choice process on consumer decision processes: A protocol analysis. J. Consumer Res. 7 (3), 234–248.

Biehal, G., Chakravarti, D., 1989. The effects of concurrent verbalization on choice processing. J. Mark. Res. 26 (1), 84–96.

Braun, V., Clarke, V., 2006. Using thematic analysis in psychology. Qualitative Res. Psychology 3 (2), 77–101.

Brewer, M.B., Crano, W.D., 2000. Research design and issues of validity. Handbook Res. Methods Social Personality Psychology 3–16.

Bushman, B.J., 1988. The effects of apparel on compliance: A field experiment with a female authority figure. Pers. Soc. Psychol. Bull. 14 (3), 459–467.

Cin, M., Değirmençay, Ş.A., 2018. Decision-making of middle school students during an earthquake. Rev. Int. Geographical Educ. Online 8 (3), 556–570.

Coburn, A.W., Spence, R.J., Pomonis, A., 1992, July. Factors determining human casualty levels in earthquakes: mortality prediction in building collapse. Proceedings of First International Forum on Earthquake related Casualties.

Cornelissen, M., 2013. How can they do it? A structured, approach to modelling performance, variability . Monash University.

Cosma, G., Ronchi, E., Nilsson, D., 2016. Way-finding lighting systems for rail tunnel evacuation: A virtual reality experiment with Oculus Rift. J. Transportation Saf. Security 8 (sup1), 101.

Dey, I., 2003. Qualitative Data Analysis: A User Friendly Guide for Social Scientists. Routledge.

Dominique, J., Aerni, A., Schelling, G., Roozendaal, B., 2009. Glucocorticoids and the regulation of memory in health and disease. Front. Neuroendocrinol. 30 (3), 358–370.

Donald, I., Canter, D., 1992. Intentionality and fatality during the King's Cross underground fire. Eur. J. Social Psychology 22 (3), 203–218.

Duarte, E., Rebelo, F., Teles, J., Wogalter, M.S., 2014. Behavioral compliance for dynamic versus static signs in an immersive virtual environment. Appl. Ergon. 45 (5), 1367–1375.

Ericsson, K.A., Simon, H.A., 1984. Protocol Analysis: Verbal Reports as Data. the MIT Press.

Ericsson, K.A., 2006. Protocol analysis and expert thought: Concurrent verbalizations of thinking during experts' performance on representative tasks. In: Anonymous. The Cambridge handbook of expertise and expert performance, pp. 223–241.

Ericsson, K.A., Simon, H.A., 1993. Protocol Analysis. MIT Press, Cambridge, MA.

Ericsson, K.A., Simon, H.A., 1980. Verbal reports as data. Psychol. Rev. 87 (3), 215.

Feng, Z., González, V.A., Amor, R., Lovreglio, R., Cabrera-Guerrero, G., 2018a. Immersive virtual reality serious games for evacuation training and research: a systematic literature review. Comput. Educ. 127 (2018), 252–266.

Feng, Z., González, V.A., Ma, L., Al-Adhami, M.M.A., Mourgues, C., 2018, November. Rapid 3D reconstruction of indoor environments to generate virtual reality serious games scenarios. Proceedings of the 18th International Conference on Construction Applications of Virtual Reality.

Feng, Z., González, V.A., Amor, R., Spearpoint, M., Thomas, J., Sacks, R., Lovreglio, R., Cabrera-Guerrero, G., 2019. An immersive virtual reality serious game to enhance earthquake behavioral responses and post-earthquake evacuation preparedness in buildings. arXiv preprint arXiv:1905.11082.

Fioretti, G., 2013. Agent-based simulation models in organization science. Organizational Res. Methods 16 (2), 227–242.

Fridolf, K., Nilsson, D., Frantzich, H., 2013. Fire evacuation in underground transportation systems: a review of accidents and empirical research. Fire Technol. 49 (2), 451–475.

Gao, Y., González, V.A., Yiu, T.W., 2019. The effectiveness of traditional tools and computer-aided technologies for health and safety training in the construction sector: A systematic review. Comput. Educ. 138 (2019), 101–115.

Gero, J.S., Tang, H., 2001. The differences between retrospective and concurrent protocols in revealing the process-oriented aspects of the design process. Des. Stud. 22 (3), 283–295.

Gill, K., Laposata, E.A., Dalton, C.F., Aguirre, B.E., 2011. Analysis of Severe Injury and Fatality in the Station Nightclub Fire. University of Delaware, Newark.

Gwynne, S., 2010. Conventions in the collection and use of human performance data. NIST GCR 10–928.

Gwynne, S., Boyce, K.E., Kuligowski, E.D., Nilsson, D., P. Robbins, A., Lovreglio, R., 2016, July. Pros and cons of egress drills. Interflam 2016.

Gwynne, S., Kuligowski, E.D., Boyce, K.E., Nilsson, D., Robbins, A.P., Lovreglio, R., Thomas, J.R., Roy-Poirier, A., 2017. Enhancing egress drills: preparation and assessment of evacuee performance. Fire Mater.

Hassan, E., 2006. Recall bias can be a threat to retrospective and prospective research designs. Int. J. Epidemiology 3 (2), 339–412.

Heliövaara, S., Kuusinen, J., Rinne, T., Korhonen, T., Ehtamo, H., 2012. Pedestrian behavior and exit selection in evacuation of a corridor–An experimental study. Saf. Sci. 50 (2), 221–227.

Hensher, D.A., Bradley, M., 1993. Using stated response choice data to enrich revealed preference discrete choice models. Marketing Lett. 4 (2), 139–151.

Isenberg, D.J., 1986. Thinking and managing: A verbal protocol analysis of managerial problem solving. Acad. Manag. J. 29 (4), 775–788.

Johnson, N.R., Feinberg, W.E., Johnston, D.M., 1994. Microstructure and panic: The impact of social bonds on individual action in collective flight from the Beverly Hills Supper Club fire. Disasters, Collective Behavior and Social Organizations 168–189.

Kinateder, M., Müller, M., Jost, M., Mühlberger, A., Pauli, P., 2014a. Social influence in a virtual tunnel fire – Influence of conflicting information on evacuation behavior. Appl. Ergon. 45 (6), 1649–1659.

Kinateder, M., Ronchi, E., Gromer, D., Müller, M., Jost, M., Nehfischer, M., Mühlberger, A., Pauli, P., 2014b. Social influence on route choice in a virtual reality tunnel fire. Transp. Res. Part F: Psychol. Behav. 26 (A), 116–125.

Kinateder, M., Ronchi, E., Nilsson, D., Kobes, M., Muller, M., Pauli, P., Muhlberger, A., 2014, September. Virtual reality for fire evacuation research. 2014 Federated Conference on Computer Science and Information Systems, 313–321.

Kobes, M., Helsloot, I., de Vries, B., Post, J., 2010. Exit choice,(pre-) movement time and (pre-) evacuation behaviour in hotel fire evacuation—Behavioural analysis and validation of the use of serious gaming in experimental research. Procedia Eng. 3, 37–51.

Kuligowski, E.D., Gwynne, S.M., Kinsey, M.J., Hulse, L., 2017. Guidance for the model user on representing human behavior in egress models. Fire Technol. 53 (2), 649–672.

Kuusela, H., Pallab, P., 2000. A comparison of concurrent and retrospective verbal protocol analysis. Am. J. Psychology 113 (3), 387.

Lambie, E.S., Wilson, T.M., Brogt, E., Johnston, D.M., Ardagh, M., Deely, J., Jensen, S., Feldmann-Jensen, S., 2017. Closed circuit television (CCTV) earthquake behaviour coding methodology: analysis of Christchurch Public Hospital video data from the 22 February Christchurch earthquake event. Nat. Hazards 86 (3), 1175–1192.

Lambie, E., Wilson, T.M., Johnston, D.M., Jensen, S., Brogt, E., Doyle, E.E., Lindell, M.K., Helton, W.S., 2016. Human behaviour during and immediately following earthquake shaking: developing a methodological approach for analysing video footage. Nat. Hazards 80 (1), 249–283.

LaValle, S.M., 2017. Virtual Reality. Cambridge University Press.

Leary, M.R., Kowalski, R.M., 1990. Impression management: A literature review and two-component model. Psychol. Bull. 107 (1), 34.

Li, C., Liang, W., Quigley, C., Zhao, Y., Yu, L., 2017. Earthquake safety training through virtual drills. IEEE Trans. Visual Comput. Graphics 23 (4), 1275–1284.

Lindell, M.K., Perry, R.W., 2012. The protective action decision model: theoretical modifications and additional evidence. Risk Anal.: Int. J. 32 (4), 616–632.

Lindell, M.K., Prater, C.S., Wu, H.C., Huang, S., Johnston, D.M., Becker, J.S., Shiroshita, H., 2016. Immediate behavioural responses to earthquakes in Christchurch, New Zealand, and Hitachi, Japan. Disasters 40 (1), 85–111.

Loomis, J.M., Blascovich, J.J., Beall, A.C., 1999. Immersive virtual environment technology as a basic research tool in psychology. Behav. Res. Methods, Instrum., Comput. 31 (4), 557–564.

Lovreglio, R., González, V.A., Feng, Z., Amor, R., Spearpoint, M., Thomas, J., Trotter, M., Sacks, R., 2018. Prototyping virtual reality serious games for building earthquake preparedness: the Auckland city hospital case study. Adv. Eng. Inf. 38 (2018), 670–682.

Lovreglio, R., Gonzalez, V., Amor, R., Spearpoint, M., Thomas, J., Trotter, M., Sacks, R., 2017. The need for enhancing earthquake evacuee safety by using virtual reality serious games. In: Proceedings of the Lean & Computing in Construction Congress, Crete, Greece, pp. 4–12.

Mahdavifar, M.R., Izadkhah, Y.O., Heshmati, V., 2009. Appropriate and correct reactions during earthquakes:“ drop, cover and hold on” or“ triangle of life”. J. Seismology Earthquake Eng. 11 (1), 41–48.

Mark, T.L., Swait, J., 2004. Using stated preference and revealed preference modeling to evaluate prescribing decisions. Health Econ. 13 (6), 563–573.

Moussaïd, M., Trauernicht, M., 2016. Patterns of cooperation during collective emergencies in the help-or-escape social dilemma. Sci. Rep. 6, 33417.

Neupert, S.D., Almeida, D.M., Mroczek, D.K., Spiro III, A., 2006. Daily stressors and memory failures in a naturalistic setting: Findings from the va normative aging study. Psychol. Aging 21 (2), 424.

New Zealand Ministry of Civil Defence & Emergency Management, 2015. Working from the same page consistent messages for CDEM - Part B: Hazard specific information - Earthquake.

Nilsson, D., Johansson, A., 2009. Social influence during the initial phase of a fire evacuation—Analysis of evacuation experiments in a cinema theatre. Fire Saf. J. 44 (1), 71–79.

Nisbett, R.E., Wilson, T.D., 1977. Telling more than we can know: Verbal reports on mental processes. Psychol. Rev. 84 (3), 231.

Peperkorn, H.M., Alpers, G.W., Mühlberger, A., 2014. Triggers of fear: perceptual cues versus conceptual information in spider phobia. J. Clin. Psychol. 70 (7), 704–714.

Perry, R.W., Lindell, M.K., Tierney, K.J., 2001. Facing the Unexpected: Disaster Preparedness and Response in the United States. Joseph Henry Press.

Pfattheicher, S., Keller, J., 2015. The watching eyes phenomenon: The role of a sense of being seen and public self-awareness. Eur. J. Social Psychol. 45 (5), 560–566.

Pornpitakpan, C., 2004. The persuasiveness of source credibility: A critical review of five decades' evidence. J. Appl. Soc. Psychol. 34 (2), 243–281.

Proulx, G., Laroche, C., Pineau, J., 1996. Methodology for Evacuation Drill Studies. Institute for Research in Construction, National Research Council Canada.

Ransdell, S., 1995. Generating thinking-aloud protocols: Impact on the narrative writing of college students. The American Journal of Psychology 108 (1), 89–98.

Raphael, K., 1987. Recall bias: a proposal for assessment and control. Int. J. Epidemiol. 16 (2), 167–170.

Risko, E.F., Kingstone, A., 2011. Eyes wide shut: implied social presence, eye tracking and attention. Attention, Perception, & Psychophys. 73 (2), 291–296.

Ronchi, E., Kinateder, M., Müller, M., Jost, M., Nehfischer, M., Pauli, P., Mühlberger, A., 2015. Evacuation travel paths in virtual reality experiments for tunnel safety analysis. Fire Saf. J. 71, 257–267.

Russo, J.E., Johnson, E.J., Stephens, D.L., 1989. The validity of verbal protocols. Memory & Cognition 17 (6), 759–769.

Salmon, P.M., Young, K.L., Cornelissen, M., 2013. Compatible cognition amongst road users: The compatibility of driver, motorcyclist, and cyclist situation awareness. Saf. Sci. 56, 6–17.

Saunders, W.L., 1997. Occupant decision making in office building fire emergencies: experimental results. Fire Saf. Sci. 5, 771–782.

Shechtman, O., Classen, S., Awadzi, K., Mann, W., 2009. Comparison of driving errors between on-the-road and simulated driving assessment: a validation study. Traffic Inj. Prev. 10 (4), 379–385.

Sherman, W.R., Craig, A.B., 2018. Understanding Virtual Reality: Interface, Application, and Design. Morgan Kaufmann, San Francisco, CA.

Stuart-Black, S., 2015. Drop, Cover and Hold is still the right action to take.

Svenson, O., 1985. Cognitive strategies in a complex judgment task: Analyses of concurrent verbal reports and judgments of cumulated risk over different exposure times. Organ. Behav. Hum. Decis. Process. 36 (1), 1–15.

Tong, D., Canter, D., 1985. The decision to evacuate: a study of the motivations which contribute to evacuation in the event of fire. Fire Saf. J. 9 (3), 257–265.

Törnros, J., 1998. Driving behaviour in a real and a simulated road tunnel—a validation study. Accid. Anal. Prev. 30 (4), 497–503.

Van Gog, T., Paas, F., Van Merriënboer, J.J., Witte, P., 2005. Uncovering the problem-solving process: Cued retrospective reporting versus concurrent and retrospective reporting. J. Exp. Psychology: Appl. 11 (4), 237.

van Rompay, T.J., Vonk, D.J., Fransen, M.L., 2009. The eye of the camera: Effects of security cameras on prosocial behavior. Environ. Behav. 41 (1), 60–74.

Wilson, T.D., 1994. The proper protocol: Validity and completeness of verbal reports. Psychol. Sci. 5 (5), 249–252.

Wilson, T.D., Hodges, S.D., 1992. Attitudes as temporary constructions. The Construction of Social Judgments 10, 37–65.

Wilson, T.D., Schooler, J.W., 1991. Thinking too much: introspection can reduce the quality of preferences and decisions. J. Pers. Soc. Psychol. 60 (2), 181.

Yang, X., Wu, Z., Li, Y., 2011. Difference between real-life escape panic and mimic exercises in simulated situation with implications to the statistical physics models of emergency evacuation: The 2008 Wenchuan earthquake. Phys. A 390 (12), 2375–2380.

Young, K.L., Salmon, P.M., Cornelissen, M., 2013. Missing links? The effects of distraction on driver situation awareness. Saf. Sci. 56, 36–43.

Zhou, J., Li, S., Nie, G., Fan, X., Tan, J., Li, H., Pang, X., 2018. Developing a database for pedestrians' earthquake emergency evacuation in indoor scenarios. PLoS ONE 13 (6) e0197964.