Proposing behavior-oriented strategies for earthquake emergency evacuation: A behavioral data analysis from New Zealand, Italy and Japan

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Abstract.
Individuals' safety in an earthquake highly depends on human reactions and emergency behaviours, especially in first evacuation phases and in urban scenarios. To increase community resilience, Civil Defense Bodies in several earthquake prone countries have defined a list of recommended behaviours to take during and after an earthquake. Following those recommended behaviours could avoid exposing people to additional risks and allow them to reach an effective help from rescuers. Nevertheless, previous studies suggested that differences between recommended behaviors and real-life actions exist and increase the probabilities of casualties. Hence, solutions to assist communities in reducing the occurrence of such "unsafe" phenomena are needed. In this work, we adopt a behavioral approach to examine spontaneous real-life behaviours observed through a database of videotapes of earthquakes from New Zealand, Italy, and Japan. The presence of response actions recommended by Civil Defense Bodies of those three Countries is also assessed. Observed behaviors are organized according to evacuation phases, and comparisons between the three Countries results are provided. An uncertainty assessment is performed to investigate the sample size impact on the proposed analysis. Finally, behavioral results are employed to trace possible valuable solutions aimed at increasing community resilience and individuals' safety, by limiting the impact of hazardous spontaneous behaviors and providing an effective support to evacuees' decisions as well as possible. Main solutions categories include assistance tools (e.g.: building components, individual devices), educational training (e.g.: by using serious games), evacuation plans according to the probable evacuation process.

Keywords. Human behaviours in emergency; earthquake evacuation; educational training; emergency management; behavioural design; urban pedestrians' evacuation

1. Introduction

Enhancing communities' safety and resilience is a key factor in reducing the number of injuries and deaths that result from earthquakes. This main objective can be achieved by fulfilling three sub-goals: (1) the design of safer environments considering behavioral factors; (2) the development of Effective Emergency Management Strategies (EEMS) based on rescuers'-damaged population cooperation; and (3) the communities' training (Alexander, 2012; Bernardini et al., 2016a; Lovreglio et al., 2018).

The design goal aims at enhancing earthquake communities' response and propose risk-reduction solutions by means of interventions on architectural spaces (on, e.g.: buildings; urban layout) and of physical (e.g.: building components including wayfinding devices) and management (e.g.: evacuation plan; first rescuers' operation) emergency facilities. This goal could be accomplished through a "behavioral design" approach, which relies on the existing data on how individuals would behave in real earthquakes (Bernardini et al., 2016a). Individual-individual and individual-post-earthquake environment interactions are analyzed to evidence possible emergency criticalities and interferences, by also means of the creation of related emergency conditions representation models. Proposed interventions should be aimed at limiting such emergency phases issues, by adapting the spaces depending on human behaviors and additionally supplying information to damaged individuals about how to correctly behave, as, for instance, the ones connected to the evacuation path and safe area choice. Since solutions proposed according to a "behavioral design" approach could ideally lead people to perform safety behaviors, related strategies could actively enhance communities resilience by supporting individuals' choices based on emergency training knowledge (which are generally entrusted to Civil Defense Bodies educational programs and recommended behaviors guidelines) (Amini Hosseini et al., 2014; Becker et al., 2017). Previous works investigate observed human behaviors in earthquakes, in both indoor and outdoor scenarios (Bernardini et al., 2016b; Gu et al., 2016; Prati et al., 2013; Rojo et al., 2017; Yang and Wu, 2012), by providing discussions on the differences due to gender, age, pre-event tasks (Lambie et al., 2016) and variations between real world response and evacuation drills (Gu et al., 2016; Yang et al., 2011). However, many of those studies do not provide a direct link between behavioral data and real-world behaviors-oriented solutions, rarely perform comparisons between different National databases, and also seem to underestimate behavioral analyses on recommended safety procedures provided by Civil Defense Bodies during the evacuation.

The second goal (EEMS) is based on the individuals' need of information in emergency conditions in order to establish better emergency actions (Kaigo, 2012; Mora et al., 2015). This goal is also connected to additional behavioral-based solutions which allow people to be apprised about current surrounding conditions, and to additionally support people by (Bernardini et al., 2017; Ikeda and Inoue, 2016; Kaigo, 2012; Mora et al., 2015): interacting with evacuees to directly suggest/remind recommended behaviors; supplying information about where to move and receive rescuers' support; putting into contact evacuees and first responders. Beyond rescuers' direct support to evacuees, dynamic evacuation guidance and assistance tools (e.g.: apps for personal devices; smart city services; interactive wayfinding signs and components) seem to be able to increase the individuals' safety because they allow people to perform supported safety behaviors, especially when they are based on real-time information exchange (Bernardini et al., 2017). Nevertheless, the development of such risk-reduction strategies needs both the design of dedicated communication networks (Gorbil and Gelenbe, 2013) and a deeper behavioral analysis devoted to understand real-life behaviors and their reference elements.

In this way, it could be possible to define which precise feedbacks on emergency behaviors should be addressed to the evacuees.

The training goal is addressed by the Civil Defense Bodies of several earthquake prone countries, such as New Zealand (MCDEM, 2015), Italy[1] and Japan[2], by providing communities with a list of recommended actions to take during and after an earthquake. As such, communities training is fundamental to make individuals aware of the best response to have during and after an earthquake. Different solutions have been proposed to train communities on how to respond an emergency which includes several pros and cons (Gwynne et al., 2017, 2016; Lovreglio et al., 2018). Evacuation drills are the most used traditional approach to train communities all around the World, see for instance the world wide earthquake drills promoted by ShakeOut (2017). The main limitation of these evacuation drills is the difference between the real-World emergency and the simulated conditions, which can dreamily limit the leaning possibilities for participants. Furthermore, the importance of such activities and the effect of similar issues on emergency effectiveness is also remarked for other kind of disasters, such as fires, flooding, terrorist acts (Knuth et al., 2017). Many training investments are done each year to enhance community's' earthquake preparedness. The main questions are: "Are those training investments effective?"; "Do individuals follows the recommended behaviors?". Few previous works suggest that differences between recommended and real-life behaviors might happen (Lambie et al., 2017; Yang et al., 2011) and so could limit the impact of safety procedures during a real emergency (e.g.: running out of building during the shake instead of performing drop-cover-hold on actions), also depending on people's previous disaster experiences (Becker et al., 2017). However, investigations and comparisons between several earthquake prone countries seem to be limited and behavioral-based remarks on training goals should be pointed out.

In this paper, we provide an answer to those requests by providing a behavioral data investigation on earthquake emergencies occurred in New Zealand, Italy, and Japan. Videotapes of several earthquakes from these earthquake prone Countries are collected to firstly organize the main noticed real-world evacuation behaviors. The proposed human actions analyses provide several insights on the frequencies of individuals following each noticed behavior (with a specific reference to recommended actions), with the additional possibility to offer a preliminary comparison of response differences in the three Countries. The uncertainty of those frequencies is also evaluated using Bayesian Statistics to investigate the impact of the sample size on the proposed analysis. In particular, we estimate the probability distributions of the estimate frequencies using Markov chain Monte Carlo sampling (Carpenter et al., 2017). Finally, based on the results of behavioral investigations, we identify some fundamental remarks on if/how it is possible to define risk-reduction strategies with the aim of encouraging people to limit the activation of hazardous behaviors or supplying them fundamental information on the surrounding scenario in relation to the main "spontaneous" behaviors. Such solutions could be founded on the enhancement of future training campaigns considering traditional and novel training tools. Additional remarks could help emergency planners and safety designers to mitigate the impact of future earthquakes on communities, by including interventions on the built scenarios, management strategies and support tools for population.

2. Phases and methods

This work is divided in two phases. The first phase consists of the analysis of real-world earthquakes videotapes, according to previous behavioral analysis studies (Bernardini et al., 2016b; Yang et al., 2011) to trace human reaction to the event and their frequencies for the three main emergency evacuation phases (pre-movement; motion towards the evacuation target; safe area reaching and immediate post-evacuation phase). Investigations on the frequencies of people who activates Civil Defense Bodies recommended safety procedures are also performed. Such methods are described in Sections 2.1 and 2.2. The uncertainty of the proposed frequencies is also quantified by adopting a Bayesian Statistics approach (Carpenter et al., 2017). Related methods are shown in Section 2.3. The first phase results are shown at Section 3.1.

In the second phase, according to a "behavioral design" and "affordance" based approach (Bernardini et al., 2016a; Carattin et al., 2016), strategies to support human evacuation are outlined according to the main behavioral analysis results, as pointed out by Section 3.2. Such strategies should be based at limiting risk-increasing behaviors, at suggesting people to perform safety procedure (or even discouraging them from carrying out hazardous actions) and at supplying main required information to the individuals while moving in an earthquake-stricken environment.

2.1. Behavioral analyses sample characterization

Videotapes of real earthquake evacuations from New Zealand, Japan and Italy are collected to investigate individuals' response during and after the earthquake shaking. Most of those videotapes were available from the Internet and were

[1] Guidelines are included in "Protezione Civile in Famiglia" by Presidenza Consiglio dei Ministri - dipartimento della Protezione Civile, 2005 (in Italian); available at: http://www.protezionecivile.gov.it/resources/cms/documents/vademecum_pc_ita.pdf (last access: 17/10/2017)

[2] A reference of these guidelines is available at: http://www.metro.tokyo.jp/ENGLISH/GUIDE/BOSAI/index.htm (last access: 17(10/2017)

downloaded to carry out the behavioral analysis as described in Section 2.2. According to previous works, each videotape is divided in one or more "scenes" (Bernardini et al., 2016b; Yang et al., 2011). "Each scene has similar evacuation conditions and involves only an evacuation" (Bernardini et al., 2016b). The "scene" also shows the earthquake shaking moment. The analyzed database is composed by 65 "scenes" which are divided for the involved Countries according to Table 1. The 75% of the scenes refers to indoor scenarios, while the 25% to outdoor ones, by including streets, building annexes and courtyards. Figure 1 summarizes the sample in terms of:

1. *referring evacuation conditions*, which are *indoor* and *outdoor* scenarios and, in addition:
    - *presence of debris*; *presence of low obstacles, like trees, shelters, street furniture, fences*: this characterization is referred only for outdoor scenarios, and is used to investigate man-environment interactions;
    - *presence of rescuers and safety staff members*: this characterization refers only to indoor and outdoor public spaces in order to assess the impact of qualified safety agents on the evacuees' behaviors (i.e.: leader effects due to rescuers);
    - *presence of more than 1 individual in the scenario*: this characterization, for both indoor and outdoor, is used to focus on social interactions presence between individuals;
2. *building intended use*: this characterization is used for both *indoor* and *outdoor* scenario, to mainly evidence behavioral differences in recommended behavior for different building use. It distinguishes between: dwellings (including hostels); offices and factories; public spaces (such as shops, cafés and restaurants, transport stations, theatres, and streets for the outdoor scenarios).

As suggested by previous works on earthquake videotapes analysis (Bernardini et al., 2016b), "scenes" are considered when all the following criteria are met:

1. the possibility to detect evacuees' actions during the procedure is ensured as long as possible;
2. the footage does not show framing problems (e.g.: deleted frames; inadequate illuminance with the possibility to not continuously track human response; excessive camera movements);
3. the confirmed geographical localization and date are available, and can be confirmed by mass-media channel, civil defense or government agencies;
4. the events have an earthquake magnitude M_L (Richter Scale) equal or higher than 5 (assessed according to USGS database available at http://earthquake.usgs.gov[3]).

All the videotapes are available at goo.gl/m1Wh43 and each database element is characterized by an identification code including the Country code and a number (which is reported in the following in curly brackets {}).

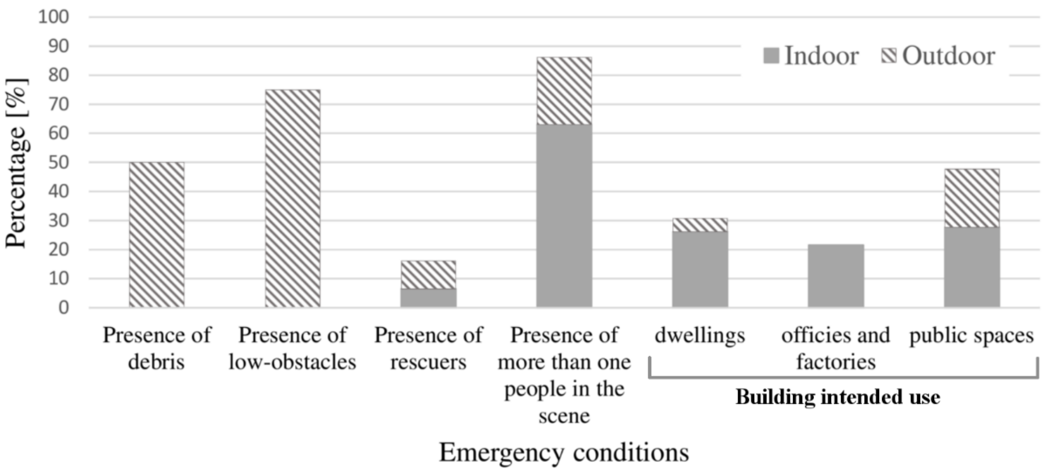

Figure 1. Characterization of the "scene" database in reference to emergency conditions, by distinguishing percentage data on indoor and outdoor scenarios.

Table 1. Number of analyzed "scenes" and involved individuals for the three Countries involved in this research, by including the percentage values.

Country [identification code for videotapes]	Number of "scenes" (percentage in respect of the whole sample)	Number of individuals engaged (percentage in respect of the whole sample)
New Zealand [NZ]	33 (51%)	76 (50%)
Italy [IT]	18 (28%)	39 (25%)
Japan [J]	14 (22%)	38 (25%)

[3] Last access: 23/02/2018.

2.2. Behavioural analyses methods

Methods adopted for behavioral analysis on the selected “scenes” are here described and based on previous works guidelines (Bernardini et al., 2016b). For each individual in each “scene”, behavioral analyses concern with:

1. *the definition of observed behaviors*: videotapes are firstly analyzed to verify if main human behaviors in earthquakes suggested by previous works occur (Bañgate et al., 2017; Bernardini et al., 2016b; Lambie et al., 2016; Rojo et al., 2017; Yang and Wu, 2012). As suggested by previous approaches to qualitative analysis in earthquakes (Bernardini et al., 2016b; Lambie et al., 2016), additional responses in emergency could exist. In particular, they could be considered as relevant if they are “present at least in the 30% of related cases”, and they also can be classified between “*common to other kinds of evacuation*” (if present in other emergency conditions) or “*specific of this case*” (if currently pointed out in reference to earthquake emergency conditions) (Bernardini et al., 2016b). For each behavior, the “reference elements” (or rather, the elements who people refer to activate the behavior) are assessed, according to previous works (Bernardini et al., 2016b; Lambie et al., 2016; Rojo et al., 2017), and they mainly are *environmental elements* (buildings and related debris, additional obstacles, evacuation paths and gathering points, earthquake shake, presence of rescuers/evacuation plans) and other *evacuees* (to activate social ties-related behaviors). All the behaviors are subdivided in the three main emergency evacuation phases: pre-movement (including the moments during the shake); motion towards the evacuation target; safe area reaching and immediate post-evacuation phase. Further remarks on particular safety procedures which are or not performed during the earthquake emergency, as shown by Table 2, are offered;
2. *the verification of recommended behaviors activation by evacuees*: national Civil Defense Bodies guidelines are organized, and videotapes are analyzed to evidence if the main recommended behaviors are performed by evacuees during the emergency process. Table 2 resumes the considered main recommended behaviors depending on the cross-Country guidelines (common recommended behaviors for the three national guidelines), and on specific national guidelines. For the investigated evacuees, it was possible to track the behaviors starting from the earthquake shaking to the evacuation phase, and there were considered safety actions only if the individual: is placed in the same scenario in which the behaviors are recommended and with reference elements present (e.g.: the “staying far from windows” action implies that windows should be present in the scene); has the effective possibility to perform the behavior (e.g.: there is a place where to cover in case of indoor earthquake) and it is possible to clearly follow his/her action to accomplish the recommended issue; engage no other recommended protection procedures (e.g.: if an evacuee stay under a table protection, protection under doorway are excluded).

In general terms, results are organized by providing this occurrence frequency (“spontaneous”/recommended) behaviors [%] referred to the same *referring evacuation conditions* (as summarized in Section 2.1): the frequencies are calculated as the ratio between the total number of “scenes” in which the behavior occurs and the total number of referring “scenes”. Data for the three involved Countries are calculated.
In addition, for analyses concerning the “*verification of recommended behavior*”, we were able to provide percentage values in relation to the number of analyzed individuals. Furthermore, such results are provided by distinguishing the whole sample (the three Countries together) and each Country data, and by additionally remarking differences between the building intended use specified at Section 2.1 that could be useful for the risk-reduction strategies proposals.

Table 2. Considered “recommended behaviors” for the three Countries involved in this research, by synthesizing the main reference cross-Country and specific National safety actions.

Country [identification code for videotapes]	Main cross-Country recommended behaviors	Additional considered recommended behaviors (according to National Guidelines)
New Zealand [NZ]	*Indoor:* During the earthquake, activate Drop – Cover – Hold procedure, and preferring to move only a few steps to the safest nearby place, staying away from windows (that may shatter and large furniture that could fall) and remaining indoors until the shaking stops. Do not rush to the stairwells and to the exits. *Outdoor:* If possible find a clear area away from buildings, trees, streetlights and power lines, especially during the earthquake. During the earthquake drop to the ground and stay there until the shaking stops.	-
Italy [IT]		*Indoor:* “Drop-cover-hold” actions could be carried out by looking for cover under the doorway.
Japan [J]		*Indoor*: Prefer hanging on building structural elements during the shaking.

2.3. Statistical methods to quantify uncertainties

In this work, we use a Bayesian approach to quantify the uncertainty of the percentage of the observed behaviors. Each observed behavior is assumed to be the number of successes in a sequence of *n* independent experiments, which can have binary results: (1) the behavior was observed and (2) the behavior was not observed. As such, the total number of time the *i* behavior has been observed (y_i) can be modelled by the binomial distribution shown by Equation 1.

$$y_i = binomial(n_i,\ p_i) \qquad \text{Eq. 1}$$

where n_i is the number of scene where the *i* behavior can be observed and p_i is the probability to observe such a behavior, which is the unknown parameter in Equation 1. Considering the sample size of the data used in this work, the Bayesian inference is used in this work to estimate p_i and to assess the uncertainty of such an estimation using a probabilistic approach (Gelman et al., 2014). In other words, the Bayesian inference generates results in terms of a probability distribution that contains uncertainty information of every plausible parameter value after observing the data. As such, it is possible to identify a range of parameter values that contains the true parameter value, which is directly interpretable and more applicable than confidence intervals (Bolstad, 2012).

Having not prior information on the possible distribution of p_i, we assume that p_i has a uniform distribution from 0 to 1 as a prior (i.e. noninformative prior). This approach is standard in the Bayesian literature and it provides a prior with minimal influence on the inference (Syversveen, 1998). Using those assumptions, it is possible to estimate the probability distribution of p_i for a given y_i and n_i. To estimate the model described in this section, we used Stan, which is a well-known Bayesian inference tool based on the Markov chain Monte Carlo method (Carpenter et al., 2017). The Markov chain Monte Carlo method is a stochastic approach to search in the parameter space the set of values that maximize the fitting of the available data. Such an approach is generally used in Bayesian analysis as it is not possible to have an analytical solution to the fitting problem. Readers can refer to (Gamerman and Lopes, 2006) for an introductory reading on this method.

The Stan code used for this study is available in Appendix A.

3. Results and discussion

This Section firstly shows the videotapes analysis results concerning observed behaviors (for the whole sample and for each Country) and the occurrence of recommended safety behaviors, by including results of the uncertainties analysis (Section 3.1). Finally, in Section **Errore. L'origine riferimento non è stata trovata.**, we try to discuss behavioral analysis results to suggest related behavioral-based remarks on possible strategies for risk-reduction in management, training, interventions on the built environment and related facilities, according to the aforementioned "behavioral-design" based approach.

3.1. Behavioural analysis results

Table 3 resumes the results of the *observed behavior* analysis on the sample "scenes" (organized according to Section 2.1) by adopting the methods proposed in Section 2.2 and the division of behaviors in the different main evacuation stages. In the following, behaviors are defined and discussed by evidencing the main linking issues during the whole procedure, by including aspects connected with Civil Defense Bodies recommended behaviors (in Section 3.1.4).

For each *observed behavior*, Table 3, an ID code is defined; following Figures 2, 3 and 4 adopt the same ID to point out he considered behavior. The *observed behavio*r is described by including the main related reference elements (*environmental elements, evacuees*) according to Section 2.2 methods and the referring evacuation conditions in the scenario according to Section 2.1 criteria. Then, the absolute and percentage frequency of the behavior is shown according to Section 2.2 definition, by offering values for each involved Country. "*Common"* and "*specific"* evacuation behaviors are evidenced according to Section 2.2 definition. In the following discussion, observed behaviors summarized in Table 3 are italicized.

Table 3. Summary of observed behaviors for the whole sample. Behaviors marked by * are "*common to other kinds of evacuation*"; otherwise, they are specific of earthquake emergency. NA refers to Not Applicable conditions because, i.e., of videotapes absence with the required referring conditions.

Evacuation phase	ID	Observed behavior	Referring evacuation conditions	Total number of scenes (total number of referring scenes) - related frequency [%]			
				whole sample	NZ	IT	J
Pre-movement phase	1	Information seeking*	Indoor; Outdoor	22 (65) – 34	13 (33) - 31	6 (18) - 33	3 (14) - 25
	2	Self-protection procedures	Indoor; Outdoor	22 (65) – 34	13 (33) - 39	4 (18) - 22	5 (14) - 36
	3	Evacuation procedure for sensible earthquakes	Indoor	43 (49) – 88	20 (24) - 83	13 (14) - 93	10 (11) - 91
	4	Attachment to things*	Indoor	15 (49) – 31	8 (23) – 35	3 (14) – 21	4 (11) - 36
	5	At least one of the following Pro-Social Behaviors*:	Indoor; Outdoor; Presence of more than 1 individual in the scenario	30 (56) – 54	16 (26) - 62	8 (16) - 50	6 (14) - 43
	6	- Information exchange, during the shake and before the evacuation starting, by means of oral and visual communication*	Indoor; Outdoor; Presence of more than 1 individual in the scenario	18 (56) – 32	8 (26) - 31	7 (16) - 44	3 (14) - 21
	7	- Social attachment, including spontaneous assistance to elderly and children*	Indoor; Outdoor; Presence of more than 1 individual in the scenario	21 (56) – 38	10 (26) - 38	7 (16) - 44	4 (14) - 29
Motion towards the evacuation target	1	At least one of the following immediate evacuation starting behaviors performed during the earthquake shaking:	Indoor; Outdoor	42 (65) – 65	20 (33) - 61	17 (18) - 94	5 (14) - 36
	2	- Moving to run out of the building (for outdoor scenarios, the analyzed data refers to visible people who exit from buildings during the earthquake shaking)	Indoor; Outdoor	39 (65) – 60	18 (33) - 55	17 (18) - 94	4 (14) - 29
	3	- Moving during the earthquake	Outdoor	11 (16) – 69	5 (9) - 56	4 (4) - 100	2 (3) - 67
	4	Evacuation stop/interruption because of ground shaking	Indoor; Outdoor	20 (65) – 31	9 (33) -27	1 (18) - 6	10 (14) - 71
	5	At least one of the following Pro-Social Behaviors*:	Indoor; Outdoor; Presence of more than 1 individual in the scenario	31 (56) – 55	17 (26) - 65	7 (16) - 44	7 (14) - 50
	6	- herding behavior and related formation of evacuation groups*	Indoor; Outdoor; Presence of more than 1 individual in the scenario	21 (56) – 38	9 (26) - 35	6 (16) - 38	6 (14) - 43
	7	- attraction for group ties*	Indoor; Outdoor; Presence of more than 1 individual in the scenario	19 (56) – 34	9 (26) - 35	7 (16) - 44	3 (14) - 21
	8	- Information exchange, during the evacuation, by means of oral and visual communication*	Indoor; Presence of more than 1 individual in the scenario	18 (56) – 32	8 (26) - 31	7 (16) - 44	3 (14) - 21
	9	Information seeking*	Indoor; Outdoor	22 (65) – 34	13 (33) - 31	6 (18) - 44	3 (14) - 21
	10	Use of personal devices during the evacuation motion including*:	Indoor; Outdoor	31 (65) – 48	15 (66) - 23	1 (36) - 3	15 (28) - 54
	11	- people using mobile devices for shooting the earthquake emergency	Indoor; Outdoor	26 (65) – 40	12 (33) - 36	NA	14 (14) - 100
	12	Attraction towards safe areas*	Outdoor	12 (16) – 75	7 (9) - 78	3 (4) - 75	2 (3) - 67
	13	Evacuation path selection in outdoor conditions	Outdoor	6 (13) – 46	4 (9) - 44	2 (4) - 50	NA
	14	Debris avoidance in outdoor conditions	Outdoor	6 (8) – 75	5 (7) - 71	NA	1 (1) - 100
	15	Fear of buildings	Outdoor	14 (16) – 88	8 (9) - 88	4 (4) - 100	2 (3) - 67

	16	*Increased guidance effect* because of rescuers and possible safety plan/signs influence*	Outdoor and indoor with presence of rescuers	4 (5) – 80	2 (3) - 67	NA	2 (2) - 100
	17	*Helplessness conditions*	Indoor; Outdoor	40 (65) – 62	19 (33) - 58	17 (18) - 94	4 (14) - 29
	18	*Attraction towards low obstacles*	Outdoor with presence of low obstacles	4 (12) – 33	2 (5) - 40	1 (4) - 25	1 (3) - 33
Safe area reaching and immediate post-evacuation phase	1	*Evacuation end* for influence of not immediate danger feelings or helplessness conditions	Outdoor	6 (13) – 46	4 (9) - 44	2 (4) - 50	NA
	2	*Safe areas definition*	Outdoor	11 (16) – 69	6 (9) - 67	3 (4) - 75	2 (3) - 67

The uncertainty of the frequencies proposed in Table 3 is analyzed using the statistical approach proposed in Section 2.3. The results related to the pre-movement phase are depictured in Figure 2 while the ones related to the motion towards the evacuation target in Figure 3. Finally, the results related to the safe area reaching and immediate post-evacuation phase are illustrated in Figure 4. The boxplots in Figures 2, 3 and 4 indicate the range of variation of the estimated frequencies. Those ranges could have different variance (i.e., uncertainty) depending from the sample size. The smaller the sample, the higher the level of uncertainty of the estimate frequencies. For instance, this trend can be clearly comparing the distributions of the whole sample to the other distributions estimated for New Zealand, Italy and Japan. In Figures 2, 3 and 4, the distributions of the whole sample (in black) have systematically a smaller dispersion than the distributions associated to New Zealand, Italy and Japan. This is explained by the fact that the total number of referring scenes (i.e. sample size) for the whole sample is always the biggest (see Table 3).

This uncertainty analysis also allows the comparison of the behavioral responses in different countries. In fact, when the thick bars, accounting for the 25th and 75th percentiles, do not overlap, it is possible to argue that there is a significant difference between the estimate frequencies. For instance, it is possible to observe from Figure 2 that there is a significant difference between the frequencies of people seeking for information (Behavior ID: 1) in New Zealand and Japan. Similar observations can be done by the remaining behavioral results in Figures 2, 3 and 4.

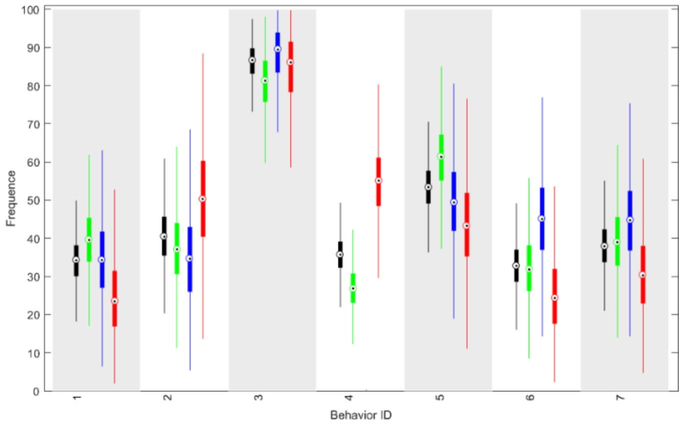

Figure 2. Uncertainty analysis of the frequencies of the behavior observed during the pre-movement phase (see Table 3 for the meaning of behavior ID; black: whole sample; green: NZ sample; blue: Italian sample; red: Japan sample – colors available in the online version)

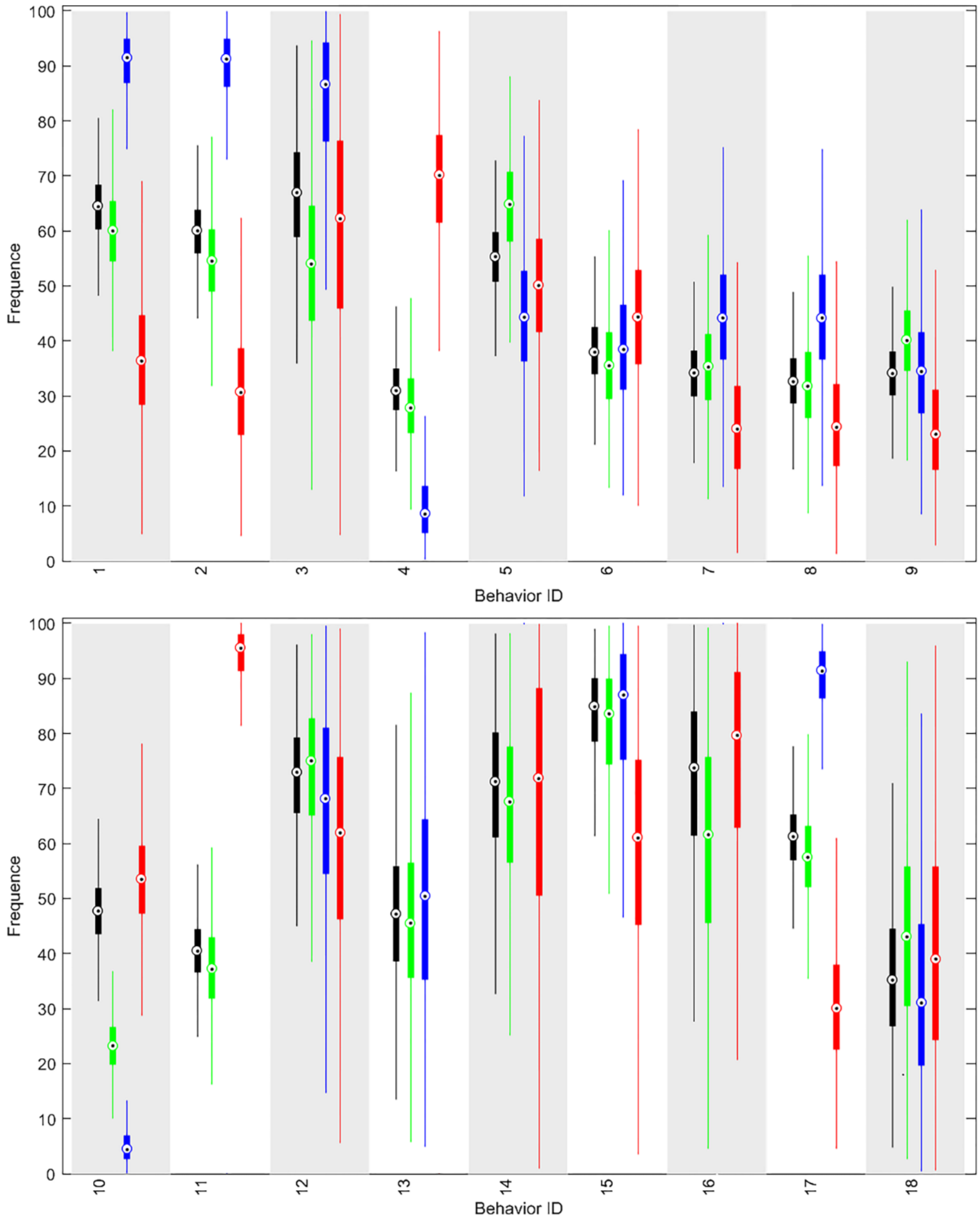

Figure 3. Uncertainty analysis of the frequencies of the behavior observed during the motion towards the evacuation target (see Table 3 for the meaning of behavior ID; black: whole sample; green: NZ sample; blue: Italian sample; red: Japan sample – colors available in the online version)

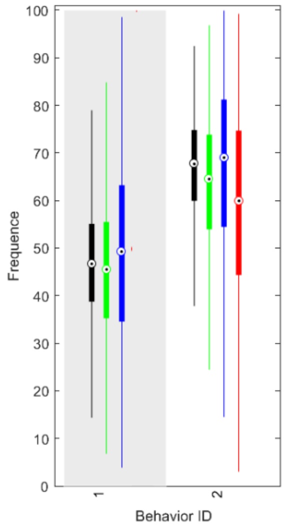

Figure 4. Uncertainty analysis of the frequencies of the behavior observed once the safe area is reached (see Table 3 for the meaning of behavior ID; black: whole sample; green: NZ sample; blue: Italian sample; red: Japan sample – colors available in the online version)

3.1.1. Influence of environment and seismic severity

Seismic severity (and shaking intensity) and surrounding environmental conditions (including building damages characterization) strongly affect human reactions to the shaking and to the following safety procedures until an individual reach a "safe" area (Bernardini et al., 2016a; Rojo et al., 2017; Solberg et al., 2008). In fact, especially in indoor scenarios, Table 3 results confirm the activation of *evacuation procedure for sensible earthquakes*, according to previous works (Akason et al., 2006; Bernardini et al., 2016b; Prati et al., 2013): the evacuation procedure generally starts for events with an intensity over the IV degree of the EMS98 scale.

According to behavioral outlines of previous works (Grünthal, 1998; Lambie et al., 2016), Table 3 shows that many people (about 60%) try to activate *immediate evacuation starting behaviors* during the earthquake (compare to behavior ID 1 in "Motion towards the evacuation target" phase in Table 3): they generally move to reach a "safe" area as, mainly, an exit in indoor conditions, by *running out of the building* (see Figure 5). In this case, they are immediately exposed to possible incoming building damages (i.e.: in indoor, furniture falling; in outdoor, non-structural building parts collapse). An example is shown by Figure 5.

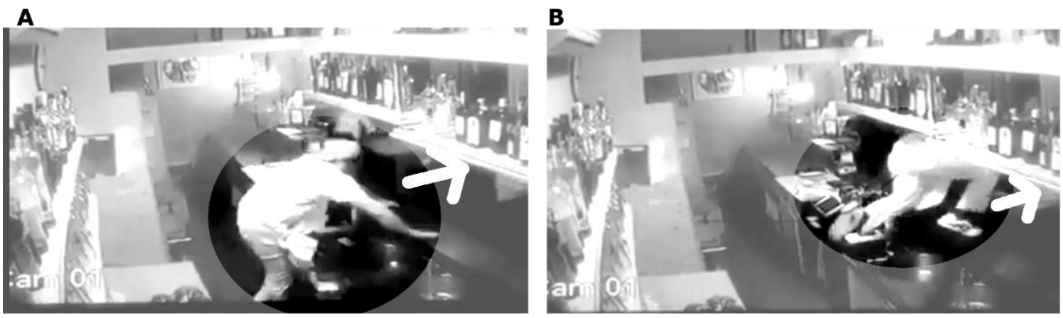

Figure 5. Immediate evacuation starting behavior: the two consecutive frames show an individual climbing over a counter and running out of the building {IT79}.

When people move outdoor, they are *attracted towards safe areas*, as for other kind of evacuations (Kobes et al., 2010), in order to restore safety conditions. Table 3 evidences this behavior in the 75% of analyzed cases for the whole sample in outdoor conditions. Similar values are shown for all the Countries. The *Safe areas definition* proposed by previous works (Bernardini et al., 2016a; Rojo et al., 2017; Santos-reyes et al., 2014) is confirmed: they are urban fabric parts in which people can gather and stop the evacuation procedure in "safe" conditions because of their geometry (i.e.: wider than the other urban fabric parts, such as large crossroads, squares, parking areas), their low visible level of damage (and safety distance from damaged buildings), and possibility to host people without crowding conditions. To reach them, people generally perform *evacuation path selection* in relation to surrounding visible building damages and geometrical dimensions of streets, as previously remarked by other studies, by preferring the "widest and clearest of dust and rubble paths" (Bernardini et al., 2016b). Such decision is strongly related to the repulsion against dangerous obstacles and serious damages induced by the earthquake (Bernardini et al., 2016b; Hu et al., 2014; Rojo et al., 2017; Tai et al., 2014): the *fear of buildings* aims individuals at maintaining a safety distance from such elements, as well as at adopting *debris avoidance* choices.

As shown by Figure 6, on the contrary, people seem to activate *attraction towards low obstacles* such as trees, enclosures street furniture, bus shelters (platform roof, also near buildings) and other similar elements (since they can also have physical support in case of intense ground shaking) and stop evacuation procedure nearby them (Bernardini et al., 2016b). This choice can be mainly associated to repulsive phenomena during motion.

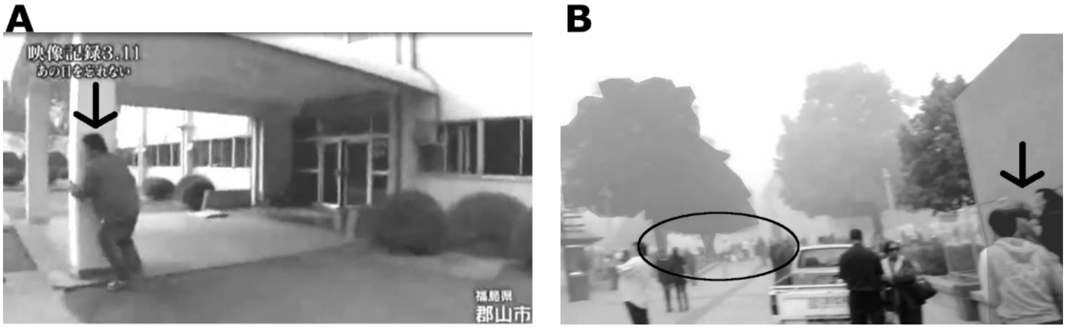

Figure 6. Examples of attraction towards low obstacles: A-during the earthquake shaking, the individual (see the arrow) allows himself to cling to a roofing column, although the element is quite near to a building (about 7m) {J27}; B-individuals move towards trees (see the ellipse) and low one-floor structures (see the arrow) and then stop evacuation procedures nearby {NZ18}.

Moreover, the ground shaking intensity can hinder human movement by provoking body instability problems and difficulties to stand and can cause *evacuation stop or temporary evacuation interruption* (Lambie et al., 2016), as shown in the 31% of cases of related behavior in Table 3.

3.1.2. Influence of social behaviours

Evacuees' decisions supported by evaluations on environmental conditions and earthquake severity are strongly affected by different attachment, cognitive and psychological phenomena during the evacuation starting (and the pre-movement reactions) as well as during the motion phase and the arrival to a "safe" area.

As for other kind of disasters, the individuals' *information seeking* (Bernardini et al., 2016b; Lambie et al., 2016) is mainly aimed at assessing the earthquake severity (e.g.: damage level, presence of injured people) in the surroundings, so as to: decide if the evacuation should start or not during the pre-movement phase; perform the evacuation path selection during the motion phase. This action is both performed by alone people and groups of individuals.

In case of group conditions and presence of ties between individuals (e.g.: family ties), *pro-social behaviors* are confirmed (Bernardini et al., 2016b; Rao et al., 2011): they imply collaborations between the individuals during the emergency response also in absence of rescuers or emergency leaders in the earthquake-stricken scenario. In this sense, *social attachment* behaviors are activated by people because of family/group bounds to retrieve support in the emergency and to increase information exchanges (Bernardini et al., 2016b; Rao et al., 2011), as for other kind of disasters (Bañgate et al., 2017; Mawson, 2007; Riad et al., 1999). **Errore. L'origine riferimento non è stata trovata.** shows two different examples of such behaviors, which are activated in relation to individuals with high vulnerability (like elderly and children; compare to **Errore. L'origine riferimento non è stata trovata.**-A) and to members of the social group (see **Errore. L'origine riferimento non è stata trovata.**-B).

According to Table 3 results, such behavior is maintained during the whole emergency process and influence the formation of evacuation group (including elements related to *"herding" behavior* (Raafat et al., 2009)) and the related gathering actions, by confirming previous studies conclusions (Bañgate et al., 2017; Lambie et al., 2016; Solberg et al., 2008). In this sense, people's group motion seems to be influenced by a sort of *attraction for group ties*, according to other kinds of disasters (Helbing and Johansson, 2010; Kobes et al., 2010; Schadschneider et al., 2009), which avoids the spatial dispersion of people in the same group during the motion procedure and the safe area reaching, in both indoor and outdoor conditions (Bernardini et al., 2016b). Examples of such group phenomena are shown by: **Errore. L'origine riferimento non è stata trovata.**-B, with reference to the final gathering of people exiting from the same building; Figure 8, with reference to the spontaneous group formation during the first evacuation stages.

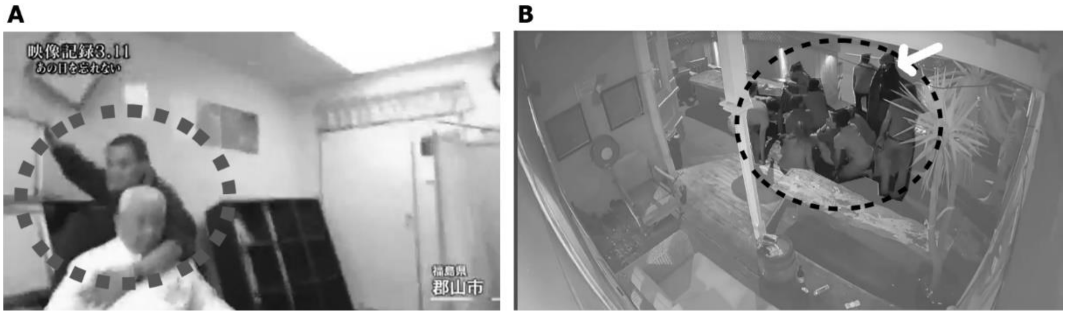

Figure 7. Examples of social attachment (in the dashed contour, people who perform the action): A-during the earthquake shaking, to protect elderly {J15}; B- at the building exit, to recreate social group at the building exit, by including an individual who is using a mobile phone (evidenced by the white arrow); in this case, people decide to gather and stop evacuation procedure in the building front courtyard {NZ34}.

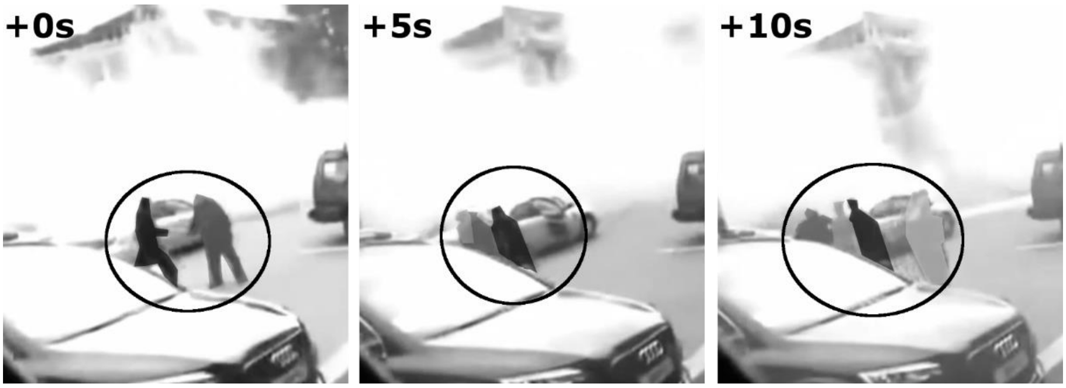

Figure 8. Example of social attachment during first emergency stages: in the three frames, a group spontaneously gathers near the same position, by collecting new members during the time, and then perform similar grouped activities {NZ9bis}.

At the same time, in case of grouped evacuees, the *information seeking* task is matched with oral and visual communications, which are fundamental elements for group decision because of *social attachment* influence (Bernardini et al., 2016b; Lambie et al., 2016; Rao et al., 2011): hence, as shown by Table 3, people activate *information exchange* procedures during the shake and before the evacuation starting as well as during their motion towards an evacuation target.

According to previous works (Bañgate et al., 2017; Bernardini et al., 2016b) and to other kind of disasters (Helbing and Johansson, 2010), emergency evacuation choices seem to be also affected by psychological issues. Evacuees seem to be engaged in a sort of *helplessness conditions* that increases group phenomena such as decision sharing (in terms, e.g., of motion choices, direction and speed), individuals' gathering and evacuation interruption. The influence of not immediate danger feelings or helplessness conditions pushes people to remain in the first available safe area, to *end evacuation* and to not perform personal safety actions. The retrieved occurrence percentage in the analyzed sample is close to the one of previous studies (Bernardini et al., 2016b).

3.1.3. Influence of belongings

According to Table 3, the occurrence of *attachment to things* behavior is confirmed (Bernardini et al., 2016b; Yang and Wu, 2012) as for other kind of disasters (Bañgate et al., 2017), by evidencing the influence of belongings on the evacuation actions and decisions. During the pre-movement phase, a combination between two phenomena is noticed: 1) holding up things during the shake in order to avoid them falling because of the shaking, especially in relation to furniture and electronic devices, by maintaining unsafe positions inside the room (see **Errore. L'origine riferimento non è stata trovata.**-A); 2) collecting belongings after the shaking, which provokes evacuation starting delays (see **Errore. L'origine riferimento non è stata trovata.**-B and **Errore. L'origine riferimento non è stata trovata.**-C).

Figure 9. Examples of attachment to things behavior: A-during the earthquake shaking, the individual (inside the dashed ellipse) holds up an armchair and the other electronic devices putted on top in order to avoid them falling {J15}; hence, the person is exposed to additional risk by maintaining an unsafe position during the devastating 11/3/2011 Japanese earthquake (M_L=9.0); B and C- an individual (marked by the arrow) spends time before evacuating the building because of personal belongings collection actions (i.e.: collecting smartphone and hat, marked by the dashed circle; time passed between frame B and C: about 5s) {NZ34}.

Table 3 shows an occurrence of such behavior in about the 30% of cases, with similar trends in the three Countries. The activation of an *attachment to things* effect is mainly related to electronic and personal devices, as also shown by previous researches (Bernardini et al., 2016b; Kaigo, 2012), and continues during the whole evacuation procedure. In fact, people firstly bring electronic devices while moving and spend time in interacting with devices (i.e.: smartphone) so as to try to look for/exchange information via mobile communication networks (e.g.: through social media platforms communications) and use *mobile devices for shooting* the emergency procedure, in both indoor and outdoor scenarios (e.g.: {J15, NZ45, NZ62, IT73}). In general terms, such phenomena are shown in about the 50% of analyzed sample cases, as shown by Table 3 (compare to behavior ID 10 and related ID 11 and 12 in "Motion towards the evacuation target" phase in Table 3). Attachment phenomena can lead people to additional risks after the shaking. In particular way, experimental data for the indoor scenarios included in Table 3 underline how the 12% of sample does not activate evacuation procedure and prefer continuing previous activities (at least, by activating self-protection procedures), especially when people are engaged in electronic devices (e.g.: personal computer) use and similar activities (Lambie et al., 2016). **Errore. L'origine riferimento non è stata trovata.** shows an example of such behavior: the individual in the scene activates safety procedures during the earthquake shaking (**Errore. L'origine riferimento non è stata trovata.**-B), but right after he gets back his previous tasks immediately (**Errore. L'origine riferimento non è stata trovata.**-C). Moreover, as shown by the example of **Errore. L'origine riferimento non è stata trovata.**-B, individuals seem to prefer the "safe" areas which are nearest to their initial positions and belongings (Bernardini et al., 2016b; Tai et al., 2014).

Figure 10. An example of missed evacuation procedure during the Wellington (NZ) 16/08/2013 earthquake (M_L=6.5): {NZ47}, by specifying the relative time gap between the frames: A-before the earthquake, the individual is playing on the computer; B-when the individual is aware of the earthquake shaking, he perform safety procedure (Drop-cover-hold); C-after the shaking stops, he returns to play and prefers not to leave the building.

3.1.4. Influence of safety procedures and recommended behaviours

In general terms, Table 3 seems to evidence that *self-protection procedure*, in reference to general actions aimed at this goal (Bernardini et al., 2016b; Lambie et al., 2016; Prati et al., 2012), are "border" behaviors and are very limited in comparison to "unsafe" behaviors like the ones connected to immediate evacuation starting during the shaking. **Errore. L'origine riferimento non è stata trovata.** offers a specific overview on the presence of recommended behaviors by considering main cross-Country guidelines, according to section 2.2 methods, by including the main links on referring evacuation phases and analyzed emergency scenario. These analyses are referred to frequency values in terms of individuals involved in such specific actions, as shown at Section 2.2.

Table 4. Presence of "recommended" behaviors for the whole sample by considering main cross-Country guidelines, and the ones of specific Country, according to Table 2 definitions. "-" implies that the condition is not noticed in the considered National sample.

ID	Recommended behavior	Referring conditions	Evacuation phase	Number of individuals performing the behavior (total number of analyses individuals) - related frequency [%]

				For the whole sample	NZ	IT	J
1	Drop	Indoor; Outdoor	Pre-movement / during the shaking	23 (156) - 15	11 (76) - 14	0 (23) - 0	12 (38) - 32
2	Cover	Indoor		14 (146) - 10	10 (76) - 13	0 (23) - 0	4 (38) - 11
3	Hold	Indoor; Outdoor		9 (138) - 12	9 (76) - 12	0 (23) - 0	3 (38) - 8
4	Complete Crop-Cover-Hold procedure	Indoor		9 (141) - 12	9 (76) - 12	0 (23) - 0	3 (38) - 8
5	Go away from buildings and other “high” elements	Outdoor	Whole evacuation	6 (16) - 38	-	6 (16) - 38	-
6	Do not rush to the stairwells and to the exits.	Indoor	Motion towards the evacuation target	9 (95) - 9	9 (62) - 15	0 (7) - 0	0 (26) - 0

The activation of at least one of the general self-protection actions during the earthquake shaking seems to be performed in a limited manner, as also suggested by the related percentage values in Table 3, and seems to be a border spontaneous behavior in such evacuation (by assuming a limit conditions for statistical significance of 30%). According to **Errore. L'origine riferimento non è stata trovata.**, during the shaking, the most performed action seems to be the DROP one, maybe also because of the possible human body instability connecting with the first moment of the earthquake. Table 4 confirms this trend in individuals’ terms. According to Table 3 and Table 4, the Italian scenario seems to be the one with the lower percentage of activate recommended behaviors, which are mainly limited to covering action under a doorway (which is a Country-specific recommended action[4]). In this last case, the “cover under a doorway” behavior is retrieved 2 times on 23 (9% of the Italian sample; this value is not included in Table 4 since this is a specific issue of a National Guideline). Nevertheless, the inquired sample is quite limited and additional videotapes referring to other Italian events should be included in the future researches. From this point of view, results confirm previous studies on the Italian cases (Prati et al., 2013), which underline the individuals’ tendency to escape from the building during the shock.

As shown byTable 2 Table 3, results also confirm that an *increased guidance effect* can be obtained by means of interaction with rescuers or other staff members with a recognizable role in the building or urban area management (e.g.: crew members at airports as shown by **Errore. L'origine riferimento non è stata trovata.**) (Yang et al., 2011). Individuals follow their evacuation instructions, such as the ones on motion direction, by identifying them as leader in the evacuation process, by increasing in this way the safe escape possibilities, likewise in other emergencies (Ma et al., 2016).

[4] Guidelines are included in “Protezione Civile in Famiglia” by Presidenza Consiglio dei Ministri - dipartimento della Protezione Civile, 2005 (in Italian); available at: http://www.protezionecivile.gov.it/resources/cms/documents/vademecum_pc_ita.pdf (last access: 17/10/2017)

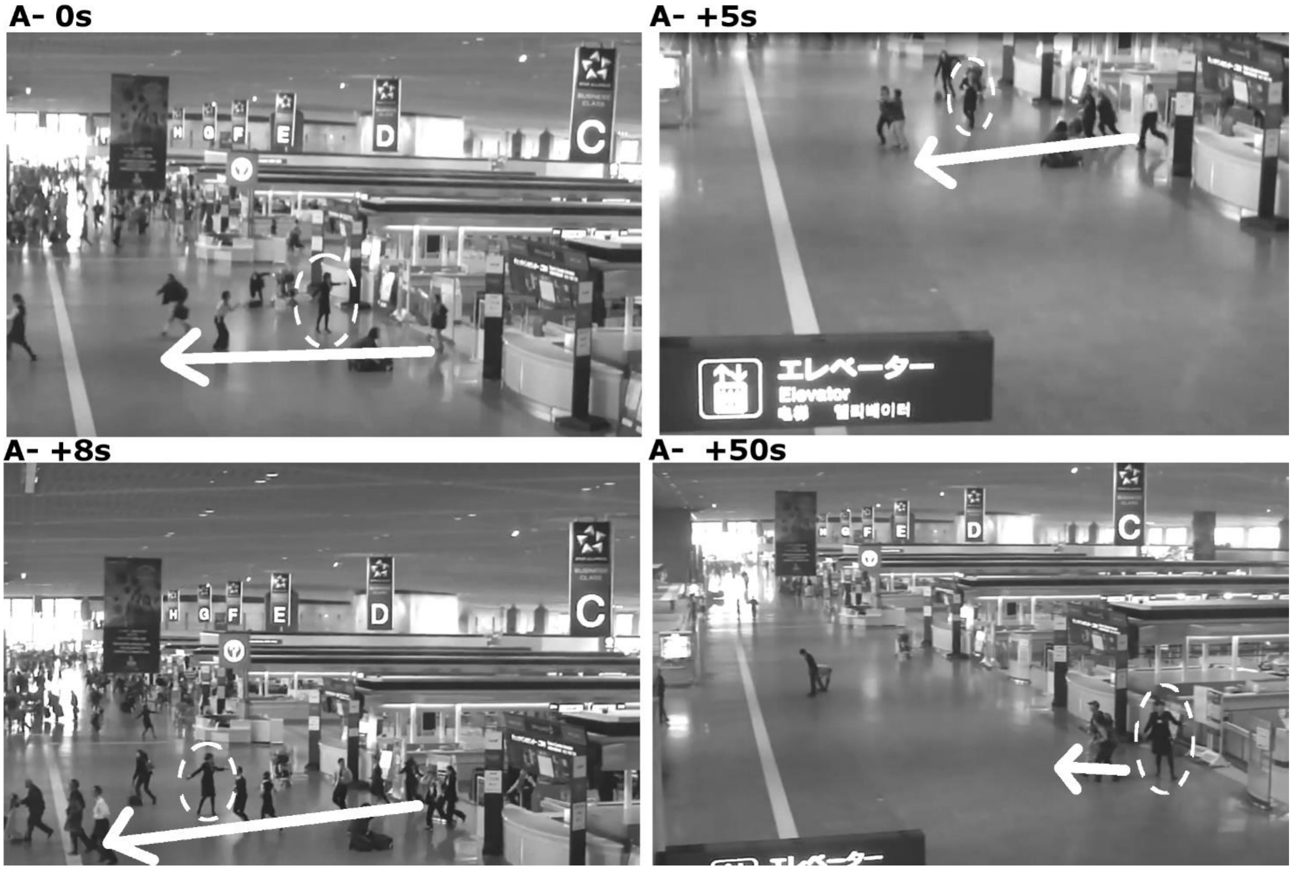

Figure 11. Increased guidance during the evacuation because of interaction with rescuers and recognizable crew members: in the four frames, the crew member (within the dashed ellipse) remains near to the initial position during the whole emergence process, points out the evacuation directions and moves close to airport occupants to stimulate their reaction {J15}.

One of the most significant behaviors stressed by *observed behaviors* in Table 3 is connected to safety distance from buildings and other "high" elements gained by evacuees, in outdoor motion. This behavior is mainly connected to the Italian case-study, as evidenced by Table 4, but, in general terms, it is spontaneously activated by people according to the fear of buildings behaviors (Bernardini et al., 2016b), as shown byTable 2 Table 3 results. People seem to prefer running out of the building instead of waiting for the shock end and not rushing at the exits, as also shown by Table 3 and Table 4 results (compare to the wide occurrence of *immediate evacuation starting behaviors* as spontaneous behaviors in Table 3) (Bernardini et al., 2016b; Grünthal, 1998; Lambie et al., 2016; Prati et al., 2013).
About specific recommended behaviors given by Japanese Civil Defense guidelines, "*Hanging on building structural elements during the shaking*", especially in case of high building shaking, is not seen in any Japanese video in the analyzed sample for indoor scenes. Anyway, individuals in outdoor can perform this action in reference to low structures elements, like the ones shown by Figure 6-A, so as to avoid stability loss during the shaking.
Finally, the uncertainty of the percentages proposed in Table 4 are analyzed using the statistical approach proposed in Section 2.3. The boxplots in Figure 12 indicate the range of variation of the estimated frequencies. Those ranges could have different variance (i.e., uncertainty) depending from the sample size and allow the comparison of those behavioral responses in different countries. The chart indicates that it is more likely to have people that drop, cover and hold (Behavioral ID: 1-4) in Japan and New Zealand than in Italy. On the other hand, it is possible to observe that people from New Zealand are more likely not to rush to the stairwells and to the exits than from Italy and Japan. Those proposed results represent a first insight on whether people follow or not the recommended behavior. However, it is worth highlighting that those results are constrain by the sample that was observed and that further investigation are required to provide generalizations of those results.

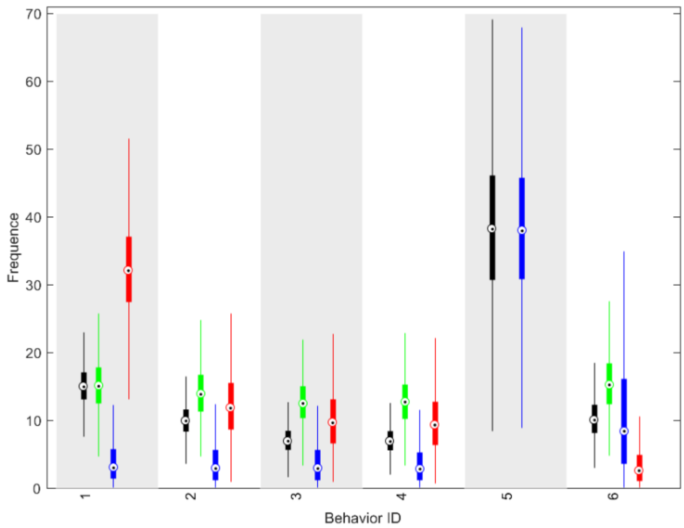

Figure 12. Uncertainty analysis of the frequencies of the presence of "recommended" behaviors (see Table 4 for the meaning of behavior ID; black: whole sample; green: NZ sample; blue: Italian sample; red: Japan sample – colors available in the online version)

3.2. Remarks on behavior-oriented solutions for evacuees

According to Section 3.1, the main key findings of behavioral analysis are the following ones:

1. a general low compliance with Civil Defense Bodies guidelines is noticed, especially during the pre-movement phase;
2. people looks for information about the event and if they are involved in potential risky conditions (e.g. during the shake; during the motion process in relation to the surrounding buildings conditions). Meanwhile, attachment to things and belongings strictly affect the whole evacuation process and could expose individuals to additional risks;
3. some safety behaviors are autonomously activated by evacuees (i.e. keeping a safety distance from buildings, moving towards safe areas, attraction towards low obstacles) while seems to ignore other simple recommended ones (e.g. cover, do not rush to stairwells and exits);
4. differences between New Zealand, Japan and Italy are slight when focusing on safety behaviors point out at point 3 of this list. Uncertainties analysis suggests that analyzed individuals in New Zealand and Japan scenes seem to be generally more aware of recommended behaviors than the ones in Italy.

In addition, such analysis allows to trace possible solutions for increasing the individuals' safety during earthquake first emergency phases, according to a Behavioral Design point of view.
In general terms, according to key findings number 1 to 3, such strategies are based on a positive interaction with activated behaviors, in order to take advantages of possible human reaction to the event so as to increase the exposed population safety, according to the adopted Behavioral Design based approach (Bernardini et al., 2016a). In this sense, they should firstly encourage the individuals' adoption of safety behaviors which are already noticed in our analyses in all the Countries, or they should support them to avoid unsafe evacuation behaviors by providing information on how to correctly react. As proposed by Section 1 topics characterization, solutions are mainly focused on proposals about education training activities of the community, about how to modify the built environment and integrate elements in the architectural spaces (i.e.: interventions on building; integration of wayfinding signage at urban scale; integration of sensors networks), and about how to provide emergency management strategies that could support evacuees during the assembly area reaching process (including interactive and individual systems).
Meanwhile, results can be used to improve existing behavioral models and emergency reaction theories. On one side, results on key finding n°4 underline the necessity to perform behavioral analyses on different geographical areas to define if similarities can be noticed in relation to such factor. Combining investigations on the impact of geographical aspects to cultural and social factors (Chu et al., 2015; Fridman and Kaminka, 2013; Galea et al., 2015) is encouraged. This study is just a first step that tries to evidence such similarities and peculiar responses when earthquake emergency occurs. On the other side, evacuation models can also take advantages of the quantification of behaviors occurrence in real events to determine more realistic representation of the earthquake evacuation process and so to validate and perform more accurate computational simulation (Bernardini et al., 2016a; Chu et al., 2015; Lovreglio et al., 2016). For instance, especially for microscopic and agent-based models (Bernardini et al., 2016a), it could be possible to define a probability of activating a specific evacuation behavior to each involved individual.
The following subsections define the common behavioral aspects to be addressed by risk-reduction strategies The title shortly characterizes the considered solution. Then, each subsection is composed by:

- *Observed behaviors*: definition of the behaviors that could be supported/limited by the strategies, according to Table 3 and Table 4 behaviors definition (and by including the ones recommended by Civil Defense guidelines);
- *Evacuation phases*: definition of the phases (according to Table 3) in which the strategies can be effective for improving human safety;
- *General compliance with recommendations of Civil Defense bodies*: discussion on how the proposed solutions are in compliance with the Civil Defense guidelines and, i.e. how they could support evacuees' safety procedures;
- *Interaction with strategies for increasing individuals' safety*: definition of the solutions according to Section 1 main typologies (communities training, built environment, effective EEMS).

3.2.1. Improving response during the shaking

Observed behavior groups: Self-protection procedures + Moving during the earthquake + Moving to run out of the building + Evacuation stop/interruption because of ground shaking

Evacuation phases: Pre-movement phase (during the shake)

General compliance with recommendations of Civil Defense bodies: After the shake, people could evaluate surrounding conditions before starting the evacuation and during the evacuation itself, by also interacting with one another

Interaction with strategies for increasing individuals' safety:

1. *communities training:* Individuals' training for increasing correct DCH procedures actuation by means of traditional training tools and emerging training tools such as Serious Games (Lovreglio et al., 2018); combination with EEMS strategies deployment and dissemination
2. *built environment:* Signaling buildings area where to find cover during the shaking in wide public spaces (e.g.: by color marks at structural elements)
3. *effective EEMS*: Widespread involvement of population by sharing information on "what to do" in case in emergency (i.e.: recommended behaviors; evacuation plan communication), by also means of electronic materials on websites and apps

3.2.2. Supply information on the event

Observed behavior groups: Information seeking + Information exchange

Evacuation phases: Pre-movement phase; Motion towards the evacuation target

General compliance with recommendations of Civil Defense bodies: After the shake, people could evaluate surrounding conditions before starting the evacuation and during the evacuation itself, by also interacting with one another. Assistance solutions should be implemented in this sense by starting from such behavioral aspects and by taking advantage of evacuees' attitude to search for information

Interaction with strategies for increasing individuals' safety:

1. *communities training:* Instruction to people on the importance about gathering information after an earthquake before starting evacuation
2. *built environment:* Inclusions of sensors networks in buildings/urban areas to perform quick estimation about structural elements, to detect the earthquake local shaking severity and to monitor the evacuation process (Dong and Shan, 2013; Rashid and Rehmani, 2016)
3. *effective EEMS*: Alerts, base instructions and information sharing to building occupants and to population via mobile phone/smartphone (including social media websites (Bernardini et al., 2017; Luna and Pennock, 2018; Zambrano et al., 2017)); use of resilient networks (e.g.: opportunistic communication; peer-to-peer communication) and smart city networks to prevent (or limit) network fall dawn and congestion (Gandotra and Jha, 2016; Gorbil and Gelenbe, 2013).

3.2.3. Limiting attachment to things effects in pre-movement time

Observed behavior groups: Attachment to things

Evacuation phases: Pre-movement phase; Motion towards the evacuation target

General compliance with recommendations of Civil Defense bodies: Collecting belongings and significant objects (i.e.: first-aid kit; smartphones; some dresses) after the shake could help evacuees during the evacuation and the first emergency phases (i.e.: during their permanence at shelters). In particular, personal devices use should not distract people from damage assessment, safe evacuation actions and movement. It is good to use smartphone to collect info regarding the overall situation, but it should not provoke network congestion (e.g.: prefer SMS to phone calls)

Interaction with strategies for increasing individuals' safety:

1. *communities training:* Instruction to people on what to prepare and pick up in case of earthquake emergency
2. *built environment:* no specific strategy
3. *effective EEMS*: As for Section 3.2.2.

3.2.4. Supporting pro-active social attachment behaviours

Observed behavior groups: Social attachment, including spontaneous assistance to elderly and children + herding behavior and related formation of evacuation groups + attraction for group ties

Evacuation phases: Pre-movement phase

General compliance with recommendations of Civil Defense bodies: Increasing the community resistance by means of spontaneous assistance between individuals

Interaction with strategies for increasing individuals' safety:

1. *communities training:* Instruction to people on the importance of collaboration to handle a safe evacuation after an earthquake. Possibility to influence the evacuees by sharing information with a group leader (Ma et al., 2016; Rao et al., 2011)
2. *built environment:* Inclusion of attachment phenomena in evacuation simulator (Bernardini et al., 2016a) so as to evaluate the impact of group choices on the individuals' safety levels and on the assembly points selection, so as to take into account the number of incoming evacuees for "safe" areas sizing
3. *effective EEMS*: Use of personal devices for interacting with the group evacuation leader ad guide him/her during the evacuation emergency procedure (Bernardini et al., 2017).

3.2.5. Limiting interaction with mobile devices

Observed behavior groups: Use of mobile devices for shooting the earthquake emergency

Evacuation phases: all the phases

General compliance with recommendations of Civil Defense bodies: This behavior has to be discouraged as well as possible

Interaction with strategies for increasing individuals' safety:

1. *communities training:* Training actions to population
2. *built environment:* Deployment of sensor (including fixed cameras) networks in the urban fabric to real-time assessment of earthquake damages and evacuation procedures
3. *effective EEMS*: Short communication (i.e.: short messages; pictures) on what an individual sees around him/her could be useful to organize the rescuers' actions in real time depending on the effective scenario modifications, to outlines points of critical situations in the urban fabric (Kaigo, 2012)

3.2.6. Supporting people to reach gathering areas

Observed behavior groups: Attraction towards safe areas + Safe areas definition + Evacuation path selection in outdoor conditions + Increased guidance effect because of rescuers and possible safety plan/signs influence

Evacuation phases: Motion towards the evacuation target

General compliance with recommendations of Civil Defense bodies: The movement of people should be aimed at gaining assembly points included in the evacuation plan, by encouraging people to use "safe" path

Interaction with strategies for increasing individuals' safety:

1. *communities training:* Spreading the evacuation plan with the population
2. *built environment:* Analysis on the built environment safety (i.e.: vulnerability; earthquake-induced damage level) and possibility to use paths in evacuation conditions without significant interferences with buildings (Bernardini et al., 2017; Zanini et al., 2017); implementation of wayfinding elements (and other safety signs, such as "assembly point" identification signs) outside the building and in the urban fabric, by also using interactive sensors/actuators networks (Bernardini et al., 2017; Carattin et al., 2016); positioning of first responders in the urban fabric
3. *effective EEMS*: Use of evacuation simulation software (based on effective earthquake behaviors and motion quantities) to define possible spontaneous assembly point and rescuers' management plan (Bernardini et al., 2016a; Hashemi and Alesheikh, 2013); spreading evacuation and emergency plan documentation through smartphone applications, as well as individuals' evacuation guidance systems to cope with hazardous spontaneous choices (Bernardini et al., 2017)

3.2.7. Supporting people while moving towards gathering areas

Observed behavior groups: Debris avoidance in outdoor conditions + Fear of buildings

Evacuation phases: Motion towards the evacuation target

General compliance with recommendations of Civil Defense bodies: It is important to stay far from building during and after the shake

Interaction with strategies for increasing individuals' safety:

1. *communities training:* Instruction to people on how to identify safe indoor and outdoor evacuation route.

2. *built environment:* Inclusion of such phenomena in evacuation simulator while defining and discussing evacuation plan and assembly points localization (Bernardini et al., 2016a; Coutinho-Rodrigues et al., 2016); interventions on buildings placed in critical places (e.g.: main evacuation paths, assembly areas) so as to encouraging people in using such spaces and perform correct evacuation movement choices
3. *effective EEMS*: Including actuation devices that can point out the building damage level to individuals or rescuers (for define the paths to be used in real time according to the current environment conditions; for first actions on post-disaster recovering, by avoiding risk assessment procedures from the outside of the building) (Coutinho-Rodrigues et al., 2016; Pierdicca et al., 2016; Xu et al., 2018)

3.2.8. Guiding people while moving

Observed behavior groups: Increased guidance effect because of rescuers and possible safety plan/signs influence + Helplessness conditions + Evacuation end for influence of not immediate danger feelings or helplessness conditions

Evacuation phases: Motion towards the evacuation target + Safe area reaching and immediate post-evacuation phase

General compliance with recommendations of Civil Defense bodies: A correct and constant support of rescuers (including remote supplying information of the emergency) could increase the evacuation procedure by reducing wrong behaviors and passiveness during the first emergency phases

Interaction with strategies for increasing individuals' safety:

1. *communities training:* Instruction to people on how to follow evacuation procedures and instructions after an earthquake
2. *built environment:* Inclusion of such phenomena in evacuation simulator (Bernardini et al., 2016a) while defining and discussing evacuation plan, assembly points localization and positioning of first responders in the urban fabric
3. *effective EEMS*: Spreading evacuation and emergency plan documentation and information about the emergency scenario through smartphone applications, as well as individuals' evacuation guidance systems to cope with hazardous spontaneous choices (Bernardini et al., 2017)

3.2.9. Taking advantages of attraction towards low obstacles

Observed behavior groups: Attraction towards low obstacles

Evacuation phases: Motion towards the evacuation target

General compliance with recommendations of Civil Defense bodies: People could move towards streets furniture and low poles, and also hanging on it in case of significant earthquake shaking

Interaction with strategies for increasing individuals' safety:

1. *communities training:* Instruction to people on how to identify safe indoor and outdoor evacuation route
2. *built environment:* Integration of evacuation signs devices in low obstacles
3. *effective EEMS*: Integration of intelligent evacuation signs and sensors/network devices in low obstacles, so as to monitor the human presence (e.g.: via Wi-Fi connection to individuals' personal devices) and guide evacuees towards safe paths and established gathering areas

4. Conclusions

The definition of safety-increasing strategies that are able to cope with hazardous conditions for population in emergencies should be based on accurate behavioral investigations. In such a way, hazardous human actions could be limited by supplying an adequate support to evacuees during the first critical phases, and in particular, during the evacuation process. This work adopts this "behavioral" point of view for earthquake emergencies in indoor and urban scenarios, by focusing the attention on three earthquake-prone Countries.

The analysis of real-world event behaviors is organized in the different emergency phases, and reference elements for human response activation are traced. The analysis of data about recommended behaviors proposed by Civil Defense Bodies evidences a general low level of application (in percentage terms) of such safety actions during emergency and then underlines the importance of evacuees' assistance solutions to support them in performing "correct" evacuation choices (e.g.: how to act during the shaking; where to find refuge during the earthquake shaking; when and where to move after the shake).

Further researches have to extend the sample dimension, by also including different Countries. In such way, specific National trends and boundary conditions in behaviors activation could be also founded, and it will be possible to evidence if the geographical impact on human behaviors is present. Additional variable to be investigated could be linked to specific characterization of the rescuers'/safety staff members' organization, as well as to analysis on social/cultural contexts. In addition, the influence of behavioral uncertainties on the outcoming results could be diminished. At the same time, quantitative investigations on human motion should be carried out, so as to link qualitative data to numeric database and to develop confident evacuation simulation models. The combination between quantitative and qualitative data on real events would allow to make the future models more effective and improve their sensitiveness to specific response behaviors, also in probabilistic terms. Such models could be then used to assess risk conditions for population because of particular behavioral choices in emergencies, and then testing the proposed safety-increasing strategies at both single building and urban scale. In addition, safety guidelines for individuals derived from such behavioral analysis should be tested in significant environment, by means of different strategies (e.g.: evacuation exercises and drills; serious virtual games), so as to verify their response effectiveness towards human choices. Finally, the proposed approach underlines its capabilities in helping safety planners while defining risk-reduction strategies, and so it could be extended to other risks at both urban and building scale (e.g.: terrorist acts; floods; hurricane).

5. Appendix A: Stan code

```
data {
int n_i; # Number of scenes where the i behavior can be observed
int y_i;  # Number of time the i behaviour has been observed
}

parameters {
real<lower=0, upper=1> p_i; # the probability to observe such a behavior (unkown parameter)
}

model {
p_i ~ uniform(0, 1); # prior distribution for p_i
y_i ~ binomial(n_i, p_i); # code definition of Equation 1
}
```

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