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EVACUATION BEHAVIOR AND FATALITY DURING THE 2011 TOHOKU TSUNAMI

Nam-Yi Yun[1] **and Masanori Hamada**[2]

ABSTRACT

The 2011 Great East Japan earthquake triggered powerful tsunami waves, causing disastrous damages in a vast area and took more than 18,000 lives. Despite the unprecedented disaster, some of the buildings and concrete bridges located in tsunami-inundated areas survived and functioned as effective shelters for those who evacuated. It indicates that the disaster could be the product of other factors such as behavioral or environmental factor. In order to study the human impact in the 2011 Tohoku tsunami, it investigates the relationships among evacuation behaviors (i.e., evacuation starting time), preparedness before the disaster, and evacuee's characteristics and survival rate of the 2011 disaster. Results show that behaviors during the disaster differentiated for the survivors and the dead and missing. A model is developed based on the analysis of each evacuation behavior factors on the fatalities; integrated strategies are proposed and discussed for the reduction of casualties in the future large-scaled natural disasters.

Keywords: *Tohoku Tsunami, human impact, evacuation behavior, fatalities*

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[1] Research Associate, Waseda University, Department of Civil & Environmental Engineering, namyiyun@aoni.waseYunda.jp
[2] Professor Emeritus, Waseda University, Department of Civil & Environmental Engineering, hamada@waseda.jp

1. INTRODUCTION

The M_W 9.0 earthquake on 11 March 2011 was generated along a very large fault area (450km length and 200km width) and constituted one of the most powerful earthquakes known to have hit Japan, and one of the five largest earthquakes by magnitude in the world (USGS, March 6, 2014). The 2011 Great East Japan Earthquake caused approximately between 16 and 25 trillion yen (around $250-500 billion USD in 2011, estimated by Cabinet Office, Government of Japan) in direct damage to social capital, housing, and private corporate facilities (White paper on Disaster Management, 2011). It also unleashed a deadly tsunami in which caused injuries, loss of lives, road and bridge damages, general property damage, and the collapse or destabilization of buildings. Among the approximately 15,000 dead and 3,000 missing, the majority was within the Tohoku area (i.e., Iwate, Miyagi, and Fukushima prefectures) and 92.5% died by drowning (National Police Agency, April 11, 2011). The affected area, Tohoku area, could be considered as one of the most prepared coastal areas in the world against a tsunami emergency, due to the awareness created by a series of recent major events – 1896 Meiji Sanriku (M 8.5), 1933 Showa Sanriku (M 8.4), and 1960 Chile (M 9.5). Additionally, tsunami preparedness in this area was clearly taken seriously by local authorities and residents, clearly indicating a high level of tsunami awareness (Esteban et al., 2013). It is clear that structural and non-structural measures should be considered and implemented simultaneously. Additionally, lessons from recent large-scale disasters show that human behavior plays a significant role in natural disaster mitigation, as well as structural and non-structural mitigation. In particular, evacuation actions taken by residents are fundamental to human damage mitigation measures against a large-scale disaster.
Hence, the present paper will investigate the behaviors on evacuation during the 2011 Tohoku tsunami. Previous researchers have analyzed survivors' evacuation behavior, but generally excluded non-survivors due to the difficulties in gathering data. In the present work the authors include several factors that influence individual coping responses using data from both survivors and non-survivors of the 2011 Tohoku tsunami. The results provide some useful information on the kind of individual behaviors that increase the likelihood of fatality due to a tsunami, which include:

- Evacuation starting time – how does the behavior of survivors and the dead and missing differ in the in response to a warning or ground shaking?
- Evacuee's characteristics (i.e., age, occupation) – to what extent do deaths have individual causes?
- Preparedness before disasters – what is the relationship between levels of preparedness with disaster prevention education and survival rates?
- Differences in behavior between groups of non-survivors and single survivors – effectiveness of tsunami evacuation principles.

2. PREVIOUS RESEARCH IN EVACUATION BEHAVIORS

Evacuation during the 2011 Tohoku tsunami was a mass movement of more than 468,600 people escaping from the earthquake-induced tsunami (March 14, 2011, National Police Agency). For effective evacuation, warnings/alarms were issued 28 times and four of these alarms were for tsunamis more than three meters in height (Ozaki, 2012). The survivors' evacuation experiences provided an opportunity to examine some of the very important practical issues regarding tsunami

evacuation. Comparative analysis between the survivors and non-survivors provide valuable insights into the factors of some very important practical issues regarding evacuation. Hence, in the present section, the authors review previous research in evacuation behavior during past tsunamis and investigate the factors that influenced the evacuation behavior of those who perished by the wave. Based on the results, conclusions can be drawn that identify behavior differences between survivors and non-survivors under the disaster, which can help to better understand how to provide a more practical mitigation strategy.

Much of the previous research on evacuation during earthquake-induced tsunamis aimed to predict who or how many evacuated, and focused on both the individual characteristics and community evacuation cues (Yun & Hamada, 2014). Researches in the individual characteristics were that characteristics - age, presence of children or elderly in the household, gender, and previous experiences with disasters - have been tested with results of a successful evacuation and showed mixed results depending on the situation (Dash & Gladwin, 2007; Yeh, 2010; Goto, 2012). Early evacuation was examined as a key factor for survival and the evacuation reasons and/or reasons for not evacuating have also been analyzed (Quarantelli, 1985; Riad et al., 1999; Sorensen, 1991). Also, the community evacuation cues analyzed the communities that facilitated evacuation through disaster prevention training and early warning systems enabled residents to safely and efficiently escape tsunami dangers (Fujinawa & Noda, 2013; Gregg et al., 2006; Papathoma et al., 2003).
In case of a tsunami event, the swift evacuation to higher grounds of each person in the coastal areas should take place as soon as a strong or extended ground shaking is felt. Yun & Hamada (2012) shows an overview of the evacuation behavior against tsunamis in Japan since 1980, in addition to illustrating the results of surveys on affected residents. Evacuation rates, defined as proportion of evacuees from the total population that evacuated, vary from place to place for the case of the same tsunami. Also, for different tsunamis the evacuation rate at a given point is different for each event. Evacuation rates did not, however, depend on the size of the tsunami wave, and ranged from 1.1% in 1982 to 89.2% in 1993. This shows that more comprehensive studies should be performed to better understand evacuation behavior.

During the 2011 Tohoku tsunami, several studies of residents' behavior were performed using survey data, but there is no common agreement on evacuation rates. For example, interviews were conducted with 870 refugees from Iwate, Miyagi, and Fukushima Prefectures through a joint investigation between JMA, the Fire and Disaster Management Agency, and the Cabinet Office of Japan using a questionnaire designed to grasp the relationship between evacuation behavior and tsunami damage. The analysis results revealed that there were 496 immediate evacuees and 267 delayed evacuees; of these evacuees, 31% after some hesitation. Also, 11% of the respondents who did not evacuate were not able to withdraw immediately. Out of the total samples, 34% went back to their houses to look for or pick up family members, and 11 % believed that it was not possible for a big tsunami to come to their area, given their own personal experience or other beliefs, such as that the presence of a strong protective breakwaters or dyke in their town would protect them. Some evacuees who hesitated to flee went to an undesignated location or to the upper floors of the building where they were at the time. This indicates that it is important to examine the time of evacuation, preparedness before a disaster, and evacuation behavior, which is analyzed in this study.

3. DATA SOURCES

Data were collected and gathered from May 18 to June 12, 2011 through the Internet and mobile telephone sites by a company specializing in weather and disaster data (Weathernews Inc., 2011). Weathernews, a company that specializes in dealing with disaster data, conducted several surveys and collected vast amounts of data using the Internet and mobile web sites. Particularly, data for behavior of the dead and missing were gathered from family, relatives, and/or friends/neighbors. As a result, Weathernews published a data report of inundated and non-inundated areas from Hokkaido, Aomori, Iwate, Miyagi, Fukushima, Ibaraki, and Chiba prefectures. It aimed to compare the evacuation behavior of the survivors and those that died using 1,153 data from the inundated area only. The percentage of the data gathered from the three prefectures most severely affected– Miyagi, Iwate, and Fukushima – was 85%: experiences from 522 people who survived and 631 people who died or were missing.

Five questions were used in the study, regarding evacuation behavior and the individual preparations that were carried out, as well as age, occupation, gender, and address: (a) How long did it take for you to start to evacuate from the tsunami?; (b) What triggered you to start evacuating? (i.e., tsunami warning); (c) What do you believe are the reason for your survival (or the death) was?; (d) What kind of disaster preparations had you taken before the tsunami disaster?; and (e) What was your Age on 11 March 2011 (or that of the person who died): (≤19, 20~29, 30~39, 40~49, 50~59, 60~69, 70~) and what was/is your (or that of the person who died) Occupation, Address and Gender?
In order to analyze the effectiveness of the tsunami evacuation principle open-ended questions were also used, allowing respondents to freely reply and further explain their behavior. It assumes that there are significant differences in behavior types and behavior frequency between survivors and the dead and missing. These differentiated behaviors of the non-survivors and the survivors can be included as potential factors explaining why some types of individuals, more than others, become victims of the disaster. In particular, the study identified two groups that show significant differences in whether they follow the tsunami evacuation principles or not. This study, therefore, considers the role of tsunami evacuation principles and compares the two groups.

4. ANALYSIS RESULTS

4.1 Evacuation starting time

Fig. 1 shows a result of the analysis using the whole data from the survivors and the dead and missing. There is a clear difference between survivors, 66% of whom evacuated within 20 minutes; this is almost double than for the case of the dead and missing, where only 35% evacuated within this time. Within the group that did not or could not evacuate there are also clear differences, as only 11% of the survivors find themselves in this category, whereas 48% of the dead and missing did not or could not evacuate.

The reasons that lead to the death of the 35% of people who evacuated within 20 minutes but still became victims include:

(a) About thirty percent of them had difficulties related to the evacuation destination (refuge), such as it being far from the residential area, or it was an unsafe refuge (i.e., a building that collapsed). In contrast with the deaths of those who had refuge-related difficulties, 11% of survivors who did not evacuate also answered that they were already in a safe location.

(b) Some individuals initially evacuated to the refuges, but about 20% went back to their houses or other places before the tsunami completely ended for a variety of purposes (i.e., move to a safer place, finding family members, collect belongings).

The above differences between the survivors and the dead and missing indicate that early evacuation to a safe location are key factors that can increase the chances of survival against a major tsunami event.

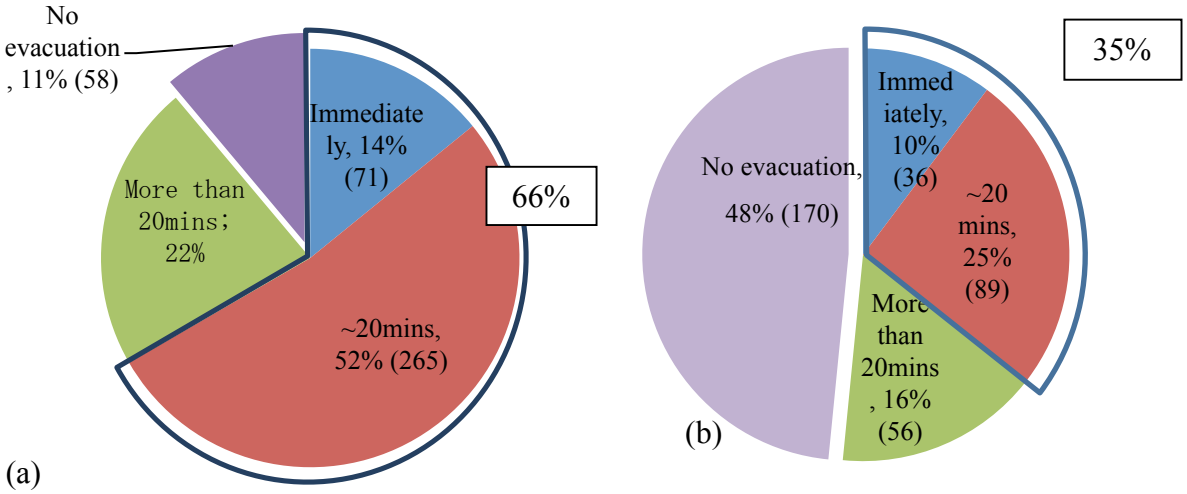

Fig. 1 (a) Evacuation starting time of the survivors (N_S: number of the survivors = 505), and (b) of the dead and missing (N_D: responses for n umber of the dead and missing = 351).

4.2 Effect of age

Age distribution for survivors and dead and missing are shown in Fig. 2. Among the survivors, 63% were less than 39 years or age, and only 3% over 60 years old. Among the dead and missing, only 29% were less than 39 years of age, and 46% were 60 years or older. The effect of age on fatality rate illustrates that people over 60 years old are more vulnerable in tsunami disasters, and is consistent with the findings in previous research (Yeh, 2010; Tatsuki, 2013).

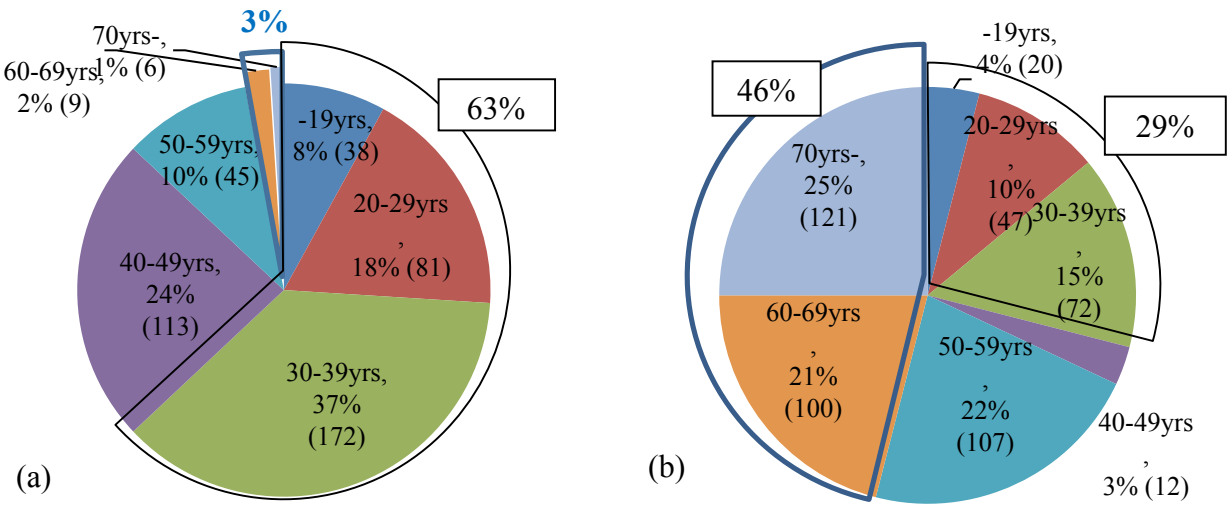

Fig. 2 (a) Age ratio of the survivors (N_S = 464), and (b) age ratio of the dead and missing (N_D = 479), using gathered data.

Fig. 3 (a) shows the evacuation starting time for the dead and missing over 60 years old. More than half (63%) did not or could not evacuate, and only 5% evacuated immediately. A possible reason for elderly people being the greatest fraction of the dead and missing persons is shown in Fig. 3 (b). Older persons had many difficulties in evacuating due to: 24% having evacuation transit difficulties (i.e., long distance to the refuge location), and 22% had physical health issues such as challenges in running fast. Furthermore, 14% had traffic issues (traffic congestion or rough roads), 12% were caring for others, and 11% other reasons (i.e., did not know where the shelters were located).

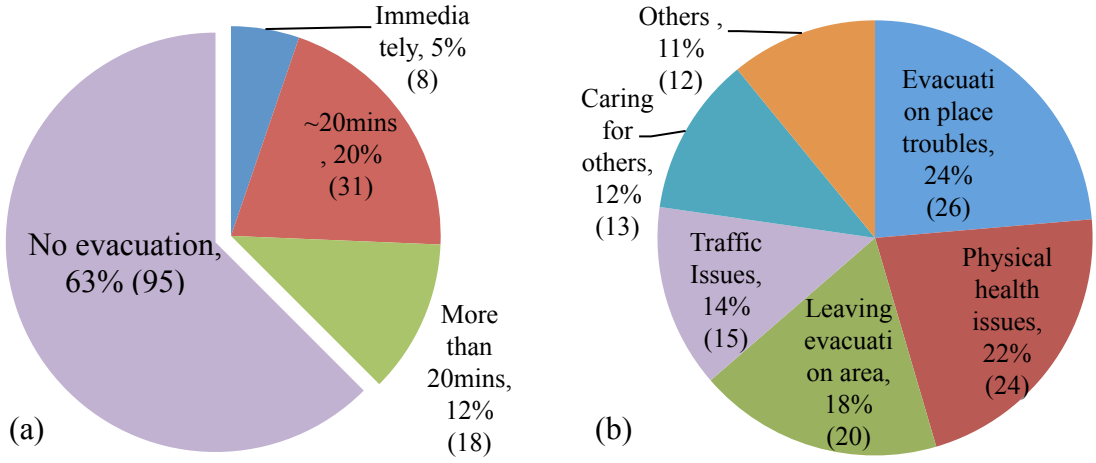

Fig. 3 (a) Evacuation starting time for those aged over 60 that died or went missing (N=152), and (b) answers to the question about the reasons why they died (N=110).

4.3 Effect of occupation

Fig. 4 shows the difference in occupation between the two groups. Office workers constituted 31% of survivors but only 21% of the dead and missing. On the other hand, housewives (29%) and shops/small businesses workers (15%) make up nearly half of the dead and missing, as shown in Fig. 4 (b). There may have been less information and guidance provided for the housewives and workers in small businesses while office workers were more likely to receive support from colleagues and their workplace. Another possible reason for housewives accounting for the highest fraction in the dead and missing persons is because most wooden houses were swept away by the tsunami (National Police Agency on April 19, 2012). Additionally, 10% of the survivors were students, but constituted 5% of the dead and missing. The reasons for this could be similar to those for the case of office workers – students were more likely to receive education on evacuation and information from teachers. It shows that people with specific occupations that could make them receive less information on evacuation and support may be more vulnerable to tsunamis.

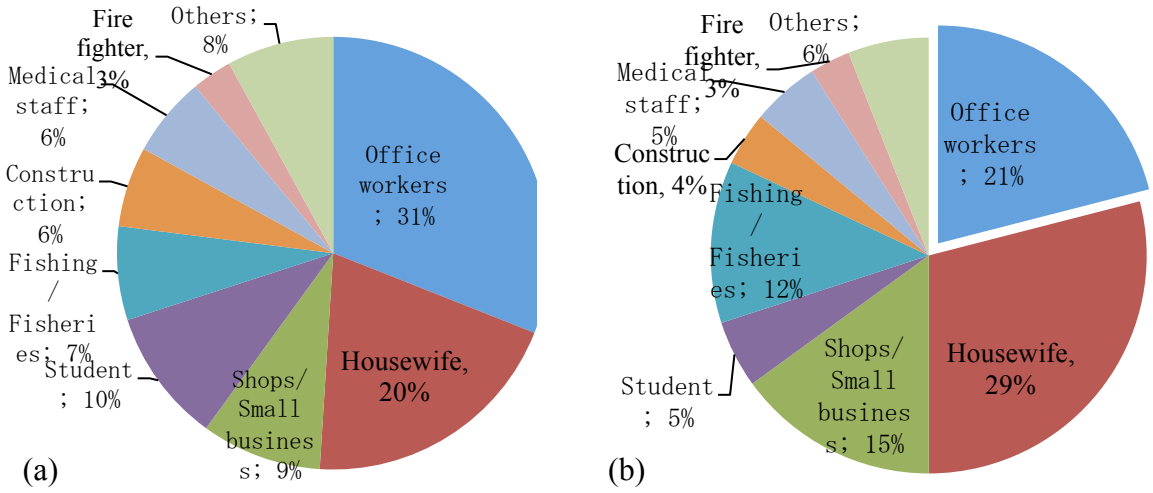

Fig. 4 (a) Survivors' occupation (N_S=394), and (b) the dead and missing (N_D=372). The above data excludes blank answers and items of less than one percent.

4.4 Predict the likelihood of death due to the tsunami

Based on the results of each of the factors, it examined who was more vulnerable to a tsunami using a regression model (Riad et al., 1999). After excluding the fully unanswered questions, the sample size was 610: 74% survivors, 48% female and heterogeneous in age (mean 36.6 years, standard deviation 15.9 years). Table 1 attempts to predict which characteristics are more likely to increase the chances of death due to a tsunami. Only the significant findings will be mentioned in the remainder of this paper.

Table 1. Prediction of what characteristics increase the likelihood of death due to the tsunami

Likelihood of Death by the tsunami	Model (1)		Model (2)	
Age	0.75**	(0.17)	0.75**	(0.17)
Gender	0.15	(0.39)	0.17	(0.39)
Inundated Place types (outdoors)	−0.06	(0.32)	−0.05	(0.35)
Evacuation Starting time	0.69**	(0.12)	0.70**	(0.13)
Preparedness	−0.1	(0.08)	–	–
Participation in disaster prevention training before the disaster	–	–	−0.87**	(0.12)
Occupation				
Office workers (reference category)	–	–	–	–
Housewife	0.49	(0.33)	0.45	(0.34)
Shops/small business	0.67**	(0.11)	0.65**	(0.08)
Students	1.92+	(1.02)	1.97*	(1.00)
Fishing/Fisheries	1.78**	(0.26)	1.77**	(0.29)
Construction	0.48	(0.74)	0.47	(0.74)
Medical staff	0.22	(0.21)	0.17	(0.23)
Fire fighter	1.58+	(0.84)	1.62+	(0.85)
Others	0.53**	(0.11)	0.53**	(0.14)

Note: Number of observation = 610 (number of survivors = 457, number of non-survivors = 153). Preparedness (participated in disaster prevention training = 4, walk evacuation route=3, know evacuation route = 2, know evacuation place = 1, none of the above = 0). Participation in disaster prevention training before the disaster (participated = 1, no participated = 0). Occupation data excludes blank answers and items of less than one percent. Standardized regression coefficients are reported. Standard errors are in parentheses. To predict the likelihood of death, a conditional logistic regression model was developed with Pseudo R^2 = 0.30, 0.31 in model (1), (2), respectively. + p<.10. * p<.05. ** p<.01.

The strong predictors are age and evacuation starting time ($p < .01$): an elderly person is more vulnerable than a younger person; and the person who starts evacuation late is in more danger than an early evacuee. As for the other leading predictors, having an occupation in the sectors of shops/small businesses, fishing/fisheries, fire fighters, or being students increases the likelihood of death, compared to office workers.

Furthermore, it shows how a person's performance on preparedness differs depending on whether s/he participates in training or not. Preparedness of model (1) and the disaster prevention training before the disaster of model (2) in Table 1 compares how the person performs when participating in training versus when s/he does not: the higher level of preparedness was not significantly as helpful compared to the lower level. Hence, Table 1 exhibits how participating in a training was only effective for survival (-0.87, $p < .01$).

In conclusion, assuming that other conditions are the same (e.g., similar tsunami wave in same community), initiating early evacuation led to a greater likelihood of survival despite a lack of preparedness. Elderly persons who had difficulty evacuating and/or those in specific occupations with no participation in training were more likely to become victims in a disaster.

4.5 Comparative analysis of evacuation behavior: ranking of behavior in survivors & non-survivors
In this chapter, evacuation-disturbance behavior is referred to as an action that led a respondent's death because of obstacles preventing their fleeing to safe places. Some of the evacuation-disturbance behavior during the disaster includes not evacuating and/or taking no action, evacuating too late, and/or being held back during evacuation. These were actions (or lack of actions) that led them to a path that brought about major injuries or death. Success-induced behavior during evacuation, in contrast, had the opposite effect. A typical example for success-induced behavior is evacuating without hesitation. This includes many cases in which no fatal damage came about as a result.

According to the definition of evacuation- disturbance or success-induced behavior, the frequencies of each of the behavior groups were analyzed. Tables 2 and Table 3 summarize ranks of evacuation-disturbance and success-induced behavior based on the frequency of such behavior.

Based on Tables 2 and Table 3, it is clear that initiating early evacuation is vital to safety in a tsunami. Regarding the success-induced behavior in Table 8, some persons who were not expecting a tsunami managed to evacuate as a result of having been verbally warned by those around them. It is therefore crucial for residents who could be affected by tsunamis to understand the importance of initiating evacuation early. Regarding the evacuation-disturbance behavior shown in Table 7, despite tsunami warnings, many persons who were on low ground at the time of the earthquake did not have time to evacuate to higher places. There were also cases of persons losing their lives due to failing to perform necessary evacuation behavior. It is furthermore important to stay in safe locations that have been designated for official tsunami evacuation. After tsunami alarms were issued, many persons relocated to refuges but then went back to their houses before the tsunami completely ended. Such evacuation-disturbance behavior placed them at considerable risk.

Table 2. Ranking of evacuation-disturbance behavior

Rank	Behavior	Frequency
1	Tied up on the road (traffic jam)	26.3%
2	Help other people	22.4%
3	Do work and duty for rescue	13.9%
4	Do not evacuate due to no/wrong information	13.7%
5	Find family/relatives	9.7%
6	Ignore warnings based on past experiences	8.9%
7	Leave the assigned place	5.1%

Table 3. Ranking of success-induced behavior

Rank	Behavior	Frequency
1	Immediately evacuated	52.5%
2	Follow other people's direction	39.4%
3	Remember former disasters	8.1%

In addition, some of the actions in Table 2 may be controversial. In Japan, "helping others" is recommended as part of the evacuation action. In the present study, however, "helping others" is viewed as an evacuation-disturbance behavior that could hold up or hamper a person during the evacuation and fail to protect his/her own life. Instead of relying only on hardware approaches such as improving and strengthening buildings, disaster prevention emphasizes software approaches such as improvements in warning systems and a more thorough evacuation education. It is difficult to change human behavior, but the rewards are clearly worth the effort.

5. DISCUSSION

The present study investigated the difference in the behavior between the survivors and the dead and missing during the 2011 tsunami, and predicted who or how many could be died, including non-survivors data in the inundated areas.

Significant differences between the survivors and the dead and missing such as age, occupation, and evacuation starting time were found in this study. The regression result described which characteristics are likely to increase the chances of death due to the tsunami. There is a highly vulnerable group constituted by the elderly and those with specific occupations that are provided with less guidance. The initial step in protecting human lives from a tsunami is the ability to evacuate to a safe place autonomously, as soon as there is any awareness that a disaster will occur. Furthermore, it is important to stay in safe and appropriate evacuation designated locations. Otherwise, those who relocated to refuges, but went further as to returning back to their houses before the tsunami completely ended, often died (Yun and Hamada, 2012b). In addition, this highlights the role of disaster education needs to urge residents to make the right decision based on the knowledge of the tsunami evacuation principles and tsunami risk. The later part was to investigate the difference of behavior between groups of the non-survivors and the survivors. After the analysis, success-induced behavior from survivors and evacuation-disturbance behavior from non-survivors were extracted. Based on the frequency of these behaviors, ranks of behavior were provided. As a result, the difference in behavior between the two groups of the dead and missing and of survivors could be differentiated. Survivors often took actions which included components of immediate evacuation. In contrast, information regarding the dead and missing showed that the 2nd most often performed action was "help others during evacuation," which controversially thus constitutes an action that could impede evacuation. The present study has some limitations. Due to the obvious difficulty in gathering

data from the dead and missing, it used witnesses' statements, people who were around them at during the evacuation process.

Unlike structures, human damage and impact depend on how people make a decision to behave during disasters. To prepare against future disasters, people can be formally trained to accurately identify whether a given behavior path would be helpful during a disaster. Therefore, this paper contributes to provide a better understanding of the factors differentiating the survivors and the dead and missing, and to better improve the estimation of fatality rate. Based on these results, more effective evacuation warning messages and preparedness against future earthquake and tsunami can be developed, considering high vulnerability groups and evacuation behavior principles.

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