Suitability of the early warning systems and temporary housing for the elderly population in the immediacy and transitional recovery phase of the 2011 Great East Japan Earthquake and Tsunami

Keywords: Great East Japan Earthquake and Tsunami, early warning systems, elderly, evacuation, temporary housing, transitional phase of recovery, vulnerability

Abstract

This paper assesses the suitability of the early warning systems and post-disaster housing for the elderly population of Japan in the immediate and transitional recovery phase of the 2011 Great East Japan Earthquake and Tsunami. Written questionnaires and informal group interviews were conducted with residents of six temporary housing complexes in Miyagi and Iwate three and half years after the disaster. The median age of participants was 70, with an age range of 48 years. We assess rates of warning receipt in the immediacy of the event, evacuation actions thereafter, and the experience of living temporary accommodation. 81% of those surveyed received at least one type of earthquake or tsunami warning, the most common being an Audio Mobile Phone (AMP) message (which is received through a smart phone), heard by 45% of the sample. Radio, siren, and AMP notifications were most effective at informing the elderly overall. 84% of recipients took action in response to a tsunami warning, with 79% of respondents evacuating their homes prior to the arrival of the first wave. During the transitional phase of recovery, residents within temporary housing highlighted issues including a lack of floor space, poor thermal insulation, solitary living environments, and reduced privacy, which lead to stressed domestic relationships within families and social groups. Recommendations are made to

consider the elderly to a greater degree not only in planning for the early warning and immediate phases of disaster, but also throughout the long-term recovery process to improve psychological and physiological well-being.

1. Introduction

Disaster Risk Reduction (DRR) and in particular people's vulnerability needs to be considered not just in terms of survival, but also in terms of their resilience in the months and years following a disaster. Herein we are concerned with the vulnerability of the elderly during the immediacy of a disaster and the transitional phase of recovery. Of particular importance during these time periods are early warning systems, including effective evacuation protocol and shelter such as temporary housing.

The distribution of casualties within disaster zones, and subsequent disparities in socioeconomics and recovery are not uniform across demography; the elderly have, in particular, been found to have a high mortality rate and vulnerability in disaster scenarios [see 1, 2, 3]. In the context of modern-day Japan – a nation with an increasing old-age dependency ratio – both of these factors have been observed in recent events of considerable magnitude, such as the 1995 Kobe earthquake [see 4, 5, 6]. Groups or individuals who are susceptible to an increased magnitude of adversity can be so vulnerable as a result of their demographic – in this case age - that they receive specific mention within the Sendai Framework for Disaster Risk Reduction [7]. There is thus a need to understand the survival and well-being of such groups throughout the disaster cycle. From education and awareness, to early warning receipt, evacuation and post disaster shelter, it is imperative to discern whether adopted strategies affect or remediate relative vulnerabilities between different groups.

In the context of early warning, Mileti [8] synthesised contemporary academic discourse on how the individuals respond to disaster information when received, and the purpose and content of warning messages. In all, 8 overarching themes are identified; regarding this study, findings 2-8 are of significance, with 6 and 7 regarded as particularly pertinent, due to the demographic in question:

2. "*Education about the warning system is needed before an event*".
3. "*Alerting needs to attract attention*".
4. *"People seek social confirmation of warnings before taking protective action"*.
5. *"Messages should contain information that is important to the population"*.
6. *"Responders should consider the demographics of affected populations when preparing warning messages."*
7. *"Access for those with disabilities must be considered when developing alert or warning systems"*.
8. *"Alerting and warning is a process, not a single act."*

A number of theoretical models can be used to further identify the modes through which individuals will respond or cope with a hazard or threat. The majority of these, particularly the Precaution Adoption Process Model (PAPM) [9] and Transtheoretical Model (TTM) [10] are tailored toward health behaviour [11]. However, Lindell & Perry's [12] Protective Action Decision Model (PADM), explores how decisions are made by individuals in an emergency setting. Using evidence from prior research into individual disaster response, the model places a strong emphasis on "predecision processes" and perceptions of "threat", and "protective action" on the part of an individual as a "stakeholder" [11]. Identifying the relative weighting, in terms of influence, of variables within the framework, such as receiver characteristics, physical environmental impediments or warning source are critical in being able to define the effectiveness of a warning system [11].

Regarding 'receiver characteristics', Mayhorn [13] suggests that a strong limitation to future EWSs can be seen with potential changes in the "perception, attention, memory, text comprehension and decision making" of people as they age. Such behaviours may influence firstly whether a message is received, as a result of choices to not invest in new technologies through which they may be transmitted, or whether any action is taken at all [13]. According to Peek [14], gaps, and a lack of thorough investigation in this research area still persist, and historical studies into the warning receipt and response of the elderly have published conflicting results [see 15-23]. Furthermore, in spite of the application of research methodologies to the vulnerability and morbidity of those aged over 60 years in a post-disaster setting, there is little literature, as yet, that has examined the influence of the increasingly technocentric approaches that are being adopted in disaster risk reduction (DRR) during the modern era. In nations with a demographic transition toward an older majority, such as modern-day Japan, this paucity in awareness is especially pertinent.

Nations further need to consider their demographics, beyond simply the immediate disaster phase, for their post disaster housing policies. The deriving, implementing and evaluating of such policies needs to be placed in the context of pre-existing housing conventions and construction capabilities; especially with the variance in temporary housing can be adopted following a disaster [24]. In some countries, including Japan, purpose-built temporary housing complexes can take the form of multiple prefabricated, shipping container-like structures assembled on site. Speed and efficiency may be considered an advantage of such capability; for example 4,000-6,000 units per month were made habitable following the 1995 Kobe earthquake [25]. However, following this event, the temporary housing in Japan faced international criticism [25], with recognition that the elderly in temporary housing complexes suffered isolation from their support systems and had a lack of funding opportunities for permanent housing [24, 25]. It is critical that post disaster housing policies take care not to lead to protracted vulnerability amongst groups with pre-existing higher vulnerability, including the elderly [24].

The Great East Japan Earthquake and Tsunami (GEJET) (also referred to as the Tōhoku-oki earthquake) provides a case study of a recent large event in a nation with both an exemplary disaster education system and a high percentage of elderly persons [26]. Japan has, for a number of years, had an increasing onus to provide for a population with an increasingly old-age dependency ratio and a rising median population age (44.4 years as of 2009) [27, 28]. The influence of age as a factor in disaster mortality was evident with the GEJET, and the disparity in fatality probability across age groups was stark in municipalities and regions where subjects had been exposed to similar conditions of wave height and tsunami arrival time [see 1]. The GEJET caused 15,782 fatalities (with additional people missing) and required the evacuation of over 400,000 displaced persons [3,29]. Across the Tohoku region, where the vast majority of the damage occurred, those over 65 comprised more than 56.7% of death toll statistics, and those over 60 comprised 64% and 68% of all male and female fatalities respectively [2, 3]. By 2050, Japan's median population age is projected rise further to 53.3 years, making an understanding of the causes of high elderly mortality and the applicability of DRR approaches to the aged paramount to the success of the nation's future mitigation strategies and disaster response [30].

Since 2007 the Japanese Meteorological Agency (JMA) has operated one of the most comprehensive earthquake and tsunami warning systems in the world [31]. The EWS forms a critical part of the nation's emergency management system, and was utilised to disseminate warnings across the Tōhoku region. The Mw9.0 earthquake triggered at 14:46:23JST on the 11th March 2011. Following the detection of earthquake P-waves at 14:46:40.2 JST, it took just 5.4 seconds for the Earthquake Early Warning system to conduct a preliminary magnitude analysis [32]. 3.2 seconds later an earthquake warning was issued, and a tsunami warning followed at 14:49: three minutes after the onset of the earthquake [31, 32]. Earthquake and tsunami warning systems require a trade off between speed and accuracy, however, and, whilst the earthquake warning was issued a number of seconds before considerable ground shaking, the initial projection for the earthquake's magnitude (M_W) was superseded 120 seconds into the event, when seismic moment exceeded 8.1M_W and seismometers became saturated due to intense shaking [33]. This intense shaking resulted in an initial dramatic underestimate of tsunami magnitude, by as much as 7 metres for the Iwate Prefecture, and 4 metres for the Miyagi Prefecture [31]. Preliminary forecasts were not updated until the tsunami was detected by a Ministry of Land, Infrastructure, Transport and Tourism (MLIT) buoy ~10km off the coast of Iwate Prefecture at 15:10, and again at 15:30 when the tsunami passed other gauges and another warning upgrade was issued with far higher estimates (Table 1) [31].

Event	Time (JST)	Magnitude (M_W) Calculation	Tsunami Height (m)
P-waves recorded	14:46:40.2	Unknown	-
First earthquake M_W calculation	14:46.45.6	4.3	-
First earthquake warning issued	14:46:48.8	7.2	-
Final earthquake M_W forecast & warning	14:48:37.0	8.1	-
First tsunami warning issued	14:49	-	6.0 (Miyagi)* 3.0 (Iwate)*
Tsunami warning upgraded	15:14	-	>10.0 (Miyagi)* 6.0 (Iwate)*
Maximum tsunami height recorded by gauge (Ofunato, Iwate)	15:18	-	≥8.0m (Iwate)†
Maximum tsunami height recorded by gauge (Ishinomaki, Miyagi)	15:25	-	≥7.6m (Miyagi)†
Tsunami warning upgraded	15:31	-	>10.0 (Miyagi)* >10.0 (Iwate)*
Maximum tsunami height recorded by gauge (Soma, Fukushima)	15:51	-	≥9.3m (Fukushima)†

Table 1: Events involved in earthquake and tsunami warning notification (data from [31, 32, 34]*). Heights reported on tsunami gauges are from those closest to the study sites. * JMA height estimate. † Recorded height, the actual height may have been greater.*

The study area in question experienced a wide range in terms of tsunami wave height and inundation, resulting from differing topography and the variable effectiveness of tsunami countermeasures running north-south along the Japanese coastline. To the north, along the Sanriku ria coastline of drowned river valleys resulted in the amplification of the incoming waves, creating run-up heights of up to 41m (study site approximate run-up heights: Rikuzentakata, ~18m; Kesennuma, ~24m; Minamisanriku, ~21m) [35, 36]. A historical understanding of high run-up heights from previous tsunami along the Sanriku coast, particularly the 1896 Meji Sanriku and 1933 Showa Sanriku events, had influenced decisions to construct hard-engineered and non-structural countermeasures across this region, in addition to the raising of low lying residential areas through the repurposing of earth removed from mountaintops [35]. Further south, the lower-lying, flatter topography of the Sendai plain resulted in a lower wave run-up height but a greater degree of lateral inundation (study site approximate wave heights: Natori, 10-12m; Nagamachi, unavailable) [35, 37]. Coastal defences, evacuation areas and designated hazard zones for the Sendai plain were less extensive and generally at lower elevations than to the north [35, 36]. As a result, fatality rates across both regions were similar, with a number of studies citing a lack of tsunami awareness (and a slow evacuation as a result), tsunami shelters at elevations below run-up height, and a general lack of high ground on the Sendai Plain as key factors [35, 37]. Engineering techniques along the Sanrki/Sendai coastlines ranged from afforestation behind dike systems, through the placing of seawalls and tsunami gates around municipal areas, to the construction of offshore breakwaters [37]. Whilst a number of these strategies were successful in buying time for individuals to evacuate - such as the Tarō's 'Great Wall' [see 38], the Fudai tsunami gate, or the Ishinomaki control forest [see 35] - the failure of many systems resulted from the tsunami's unexpectedly large run-up heights. These failures have since raised questions as to whether sea defences in the GEJET created a 'moral hazard': negatively influencing the choices of individuals to evacuate due to a perception that engineered defences were sufficient protection [see 29, 39, 40].

As with its early warning system and evacuation planning, Japan has a generally well-regarded capacity to provide temporary housing following a disaster [24]. Temporary housing provision has been a staple of the Government of Japan's (GoJ) natural and anthropogenic disaster policy since the creation of the *Disaster Relief Act* in 1947 [41]. It is a law through which the GoJ is mandated to provide assistance to "persons who have been subject to a disaster… and require Relief Activities within the territory of a municipality" [42]. A number of different types of temporary home can be utilised by the GoJ following a disaster, ranging from purpose-built accommodation, to the rental of pre-existing housing outside of a disaster zone, or the use of pre-existing government or public housing [25, 43]. For a review of the temporary housing policies adopted, the reader is referred to Faure Walker and Crawford [24].

Following the GEJET's "emergency period" – a phase in which "normal social and economic activities cease or are drastically changed" [see 44] - and in line with the *Disaster Relief Act*, large-scale temporary housing complex (THC) projects were adopted by prefectural governments across Japan's Honshu Island to accommodate a share of the displaced population [43]. These were governed by the *Building Standards Law* of 1970, which states that temporary disaster housing in Japan should accommodate people for a maximum of two to three years and to adhere to minimum, government-prescribed, standards of quality and spending [4, 45, 46]. Almost four years on, however, and despite the employment of a state-wide transitional disaster recovery programme - which had aimed to construct 29,000 permanent municipal houses by 2016 through the establishment of a Japanese Reconstruction Agency (JRA) - almost 36,000 of the displaced remained within the THCs across Miyagi [43, 46, 47]. Furthermore, a lack of major disasters in Japan since the Kobe earthquake, 1995, had resulted in the majority of new or amended temporary housing design strategy and policy being untested until the GEJET, when large-scale implementation was required. Previous studies had highlighted serious issues in the Kobe temporary housing strategy, particularly in the allocation and physical design of structures, in addition to the location of complexes, which were often far from basic amenities [25, 48]. Much accommodation was allocated on a 'lottery' basis (which led to the separation of families and high percentages of solitary elderly residents), had limited living space within individual units (20-30m^2), and was negatively perceived by older residents [25, 45, 48]. Long residency periods in Kobe complexes were found to increase the risk of health complications or exacerbate underlying conditions, both physical and psychological, and in a number of cases were thought to lead to '*kodokushi*' - solitary and unnoticed death [5]. Extended residency periods within the THCs were related to local prior conditions including residents' ages and income [24]. Thus, knowing the pre-existing factors affecting vulnerability – including demographics of the residents – is essential when planning post disaster housing strategy [24].

This paper assesses the applicability to the elderly of Japan's crisis management strategies in terms of early warning systems (EWS), evacuation, and post-disaster temporary housing following the Great East Japan Earthquake and Tsunami. Three key themes are investigated among the survivors in the temporary housing complexes: (a) the suitability of media used by the Japanese Meteorological Agency (JMA) to disseminate earthquake and tsunami warnings for notifying the elderly; (b) the efficacy of early warning systems as a tool for promoting evacuation actions amongst the elderly; and (c) the relative suitability of the physical structure of temporary housing for the elderly in the longer-term aftermath of the event. It should be noted that in distinguishing between elderly and younger populations, this study adopted the

UN-accepted definition of an elderly individual as an individual “aged 60 years or over” [49].

2. Methods

Between 2nd and 5th November 2014, six temporary housing complexes (THCs) along Tohoku’s coastline were visited. Five complexes were in Miyagi, one was in Iwate (Rikuzentakata) (Figure 1). Prior arrangements were in place for a group of residents to be available in the housing complex common rooms to fill in written surveys (at five complexes) and follow this with informal oral whole group interviews and discussions (at all six complexes). The size of complexes ranged from 23 units (Kesennuma, Miyagi) through to 2,150 units (Rikuzentakata, Iwate). At the time of the interviews, all 78 respondents were still living in the temporary housing complexes, and were aged over 40 (Table 2). Three of the respondents interviewed were from temporary housing complexes in Miyagi, and were visiting the complexes that were surveyed – hence their location is listed as ‘other’.

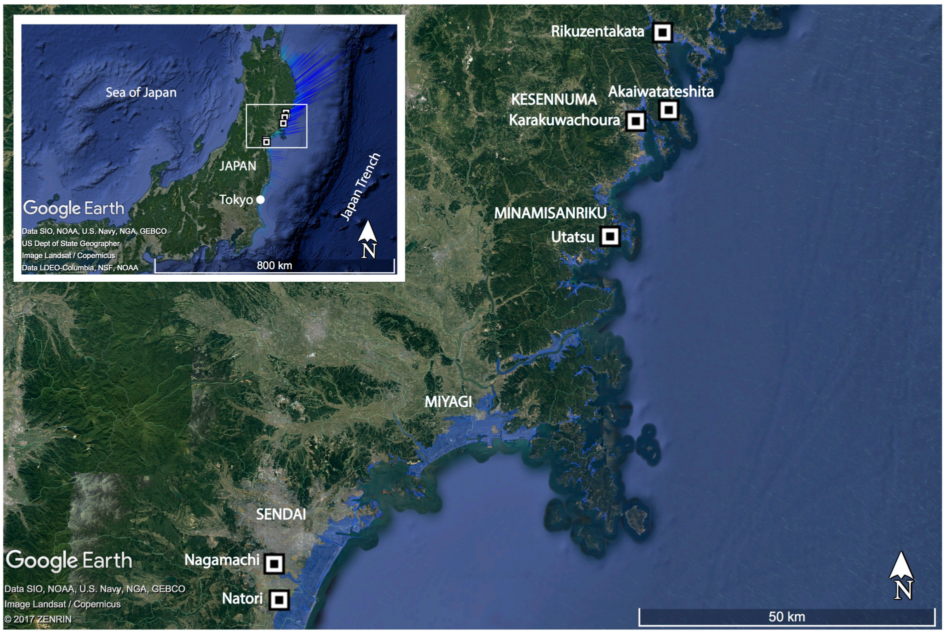

Figure 1: Map showing locations of temporary housing complexes. Insert map shows location of larger map. Blue lines on insert show tsunami run-up heights [50]. *Inundation extent of the tsunami is shown on the higher resolution map* [51].

The written surveys had 34 or 35 questions focused on gathering quantitative information regarding early warning notification receipt, evacuation and temporary housing experience following the GEJET. (Note that for ethical purposes there were two versions of the survey, and local leaders were consulted so that they could decide whether potentially more sensitive questions were appropriate). The questionnaire comprised a mixture of multiple choice, one word and open-ended questions. These were written and answered in Japanese and later translated into English. The questionnaires were conducted anonymously.

Following the filling in of the written questionnaires, informal semi-structured group interviews and discussions were held so that broader questions could be asked regarding the perception of the GoJ's temporary housing solutions, and the longer-term plans of individual residents within the complexes. These lasted between one and two hours (depending upon group sizes) and were held with all respondents within each complex (except in Kessenuma, only a selection of respondents were present for the discussions following the survey as some extra residents had completed the written questionnaire in advance). These focus groups lasted between one to two hours and were conducted with the assistance of a translator. As with the written questionnaire, all comments were kept anonymous.

Complex	Nº Questionnaires	Avg. Age of Respondents	Respondents Where Age Not Disclosed			Nº Respondents <60 Years Old			Nº Respondents ≥60 Years Old			Mean Response, All Questions (%)
			Male	Female	Gender Not Stated	Male	Female	Gender Not Stated	Male	Female	Gender Not Stated	
Sendai - Nagamachi	3	69	0	0	0	0	0	0	0	2	1	84
Kesennuma - Karakuwa	45	66	1	2	1	5	7	0	13	15	1	62
Kesennuma - Akaiwa	7	71	0	1	0	1	0	0	1	3	1	53
Minamisanriku - Utatsu	9	77	0	0	0	0	0	0	2	7	0	90
Sendai- Natori	11	72	0	1	0	0	0	0	5	4	1	83
Miyagi – Other (A)	1	53	0	0	0	1	0	0	0	0	0	85
Miyagi – Other (B)	2	56	0	0	0	1	0	0	0	1	0	55
Iwate - Rikuzentakata	0	-	-	-	-	-	-	-	-	-	-	-
Whole Sample	78	68	1	4	1	8	7		21	32	4	84

Table 2: Temporary housing complexes visited were in the municipalities of Sendai (Nagamachi), Kesennuma (Karakuwa), Kesennuma (Akaiwa), Minamisanriku (Utatsu), Rikuzentakata and Natori City. Rikuzentakata was used exclusively for group interviews, and as such no questionnaire data was taken. Sites (A) and (B) refer to THCs not visited. Figure 1 provides a location map.

The average age of respondents was 68, with a range of 48 years and a median age of 70 (25 years above the national value). 30 and 43 questionnaire respondents were male and female respectively, with the remaining 5 not disclosing their gender. 21 of the male and 32 of the female respondents stated they were aged 60 years or older (6 subjects chose not to disclose their age). Due to both the routine of life within THCs, and a desire to focus upon elderly individuals specifically, weekday afternoons were chosen for the timing of visits. However, in order to provide comparisons with middle age groups (40-60 years), some younger residents were asked to complete the questionnaire. Assistance was given during the surveys to those who needed help scribing due to frailty, and translating for a few cases of limited literacy in the survey form. Opportunist sampling was the primary method of data collection, this stemmed from the need to ensure a maximum response rate within the time available.

Fisher's exact test and the Benjamini Hochberg procedure to assess False Discovery Rate were used to identify whether age was of statistical significance in warning receipt. The Fisher's exact test used the UN [49] definition of elderly (60 years and above) to create nominal variables either side of this threshold and tested possible correlation against warning media with a significance level of $p = <0.05$; the Benjamini Hochberg procedure was used to solve the multiple comparisons problem.

3. Results

3.1 Tsunami and earthquake early warning

Across the study, 81% of respondents received either a tsunami or an earthquake warning; 62% received both a tsunami and earthquake alert. 73% of questionnaire respondents received a tsunami warning, with 71% receiving an earthquake notification prior to experiencing ground shaking. 19% of participants (almost one in five) failed to receive a warning of any sort. When separated by specific media, the tsunami warnings via audio mobile phone (AMP) (received only through smart phones) and radio messages informed the largest proportion of the sample, with figures recorded at 40% and 22% of sample respondents respectively. Earthquake warning media were more uniformly pervasive between different media; radio warnings, official word of mouth, and sirens were received by 16-17% of the sample. AMP messages were somewhat less well distributed for earthquake warnings, reaching just 13% of sample respondents (Figure 2).

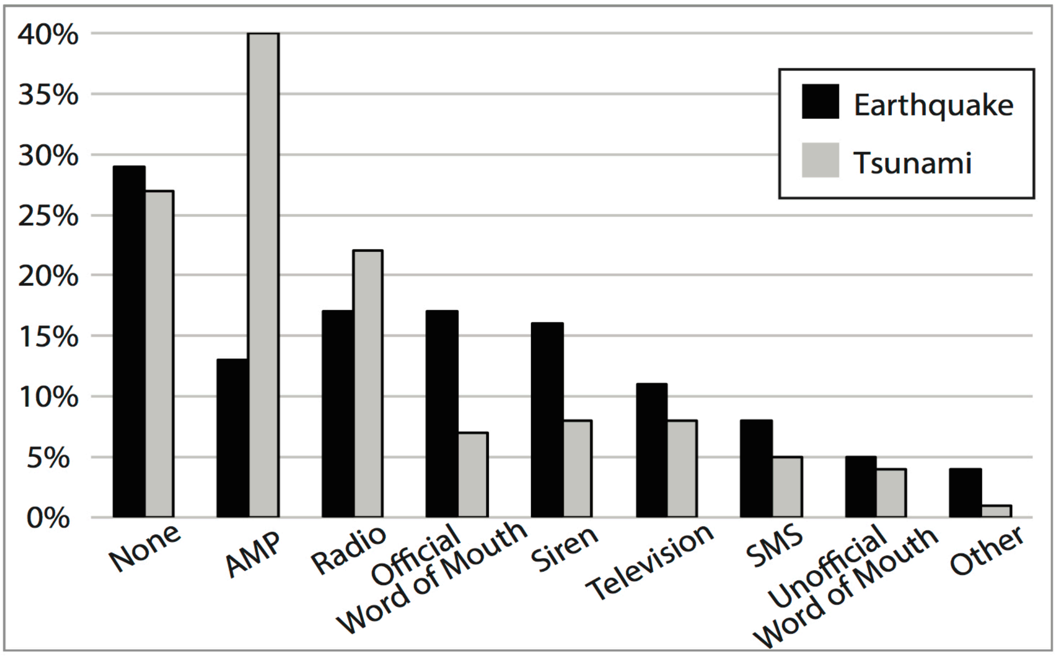

Figure 2: Graph illustrating warning media received, separated by hazard type. For tsunami warning, AMP (audio mobile phone) was the most prevalent warning, followed by radio. For earthquake warning, official word of mouth, radio and siren warnings were the most prevalent. 77 and 75 respondents from a sample of 78 responded about their tsunami and earthquake warning media respectively. As some respondents received multiple warnings, the total number of warnings received can exceed 100% of the study sample.

A number of residents cited factors in the built and geographical environment in accounting for non-receipt of warnings. Specific issues raised included the deadening effect of topography on sirens in agricultural areas; the soundproofing of windows near Sendai Airport; and the failure of power relays and signal masts in the immediacy of the earthquake. The latter affected the transmission of tsunami warnings particularly, rendering a number of media reliant upon grounded electricity or telecommunications redundant.

Partitioning rates of notification between those below the age of 60, and those aged 60 years or above produced mixed results. Various earthquake warning media were found to be less effective at informing the elderly across the sample, particularly SMS, television, and audio mobile phone messages. However, compared to the under 60s, a higher percentage of the elderly received at least one notification – 74% of sample respondents compared to 67% for the under 60s. This disparity was greater for tsunami warnings; 76% of elderly respondents received at least one tsunami warning relative to just 60% for those under the age of 60. Regarding specific media, audio mobile phone messages (AMP), SMS and sirens were most pervasive among the elderly when analyzing tsunami warnings (Figure 3).

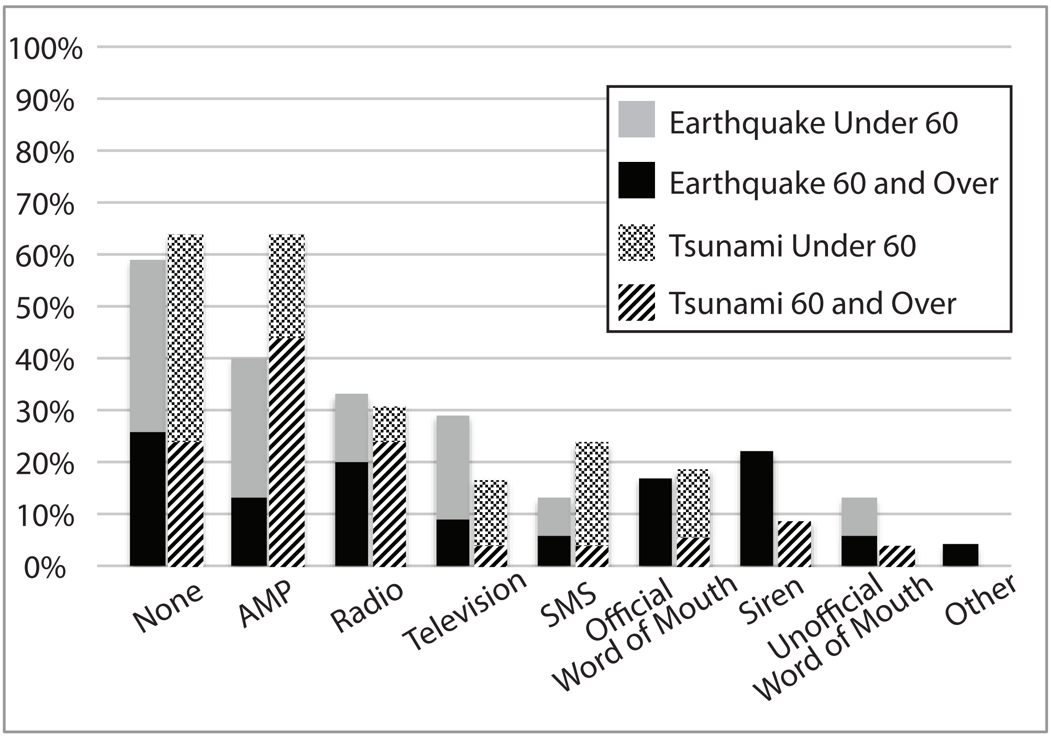

Figure 3: Rate of warning receipt and medium separated by age group and hazard type. As some respondents received multiple warnings, the total number of warnings received can exceed 100% of the study sample.

Using Fisher's exact test, the recorded difference in non-receipt of any warning between the two age categories was found not to be statistically significant at the 0.05 level ($p = 0.143$); suggesting that there may have been sufficient media variants to inform both age groups equally effectively. This hypothesis was supported by media-specific statistical analysis; where in seven of the eight categories media tested ('other' was excluded as it is not media-specific) age was found to not be a significant factor for either tsunami or earthquake warning media. For one category - 'siren' - with tsunami and earthquake warnings combined, a p-value of 0.042 indicated significance, however, application of the Benjamini Hochberg procedure for multiple comparisons found this to be a false positive.

3.2 Evacuation and actions taken

84% and 89% of recipients within the sample respectively took some form of action in response to either a tsunami or earthquake warning. 80% and 77% of respondents aged ≥ 60 years and < 60 years respectively evacuated prior to the tsunami's arrival (Figure 4). 42 respondents gave specific details on their actions upon receipt of a tsunami warning. 29 respondents (69%), 23 of which were aged 60 or over, indicated that they adhered to principles of *tsunami tendenko* – specifically stating that they immediately moved to higher ground or vertically evacuated. 5 respondents' answers (12%) were not indicative of evacuation of any sort: 3 (7%) wrote that they returned to their homes. One respondent in the Karakuwa housing complex closed the water gates of their community. In total, 89% of survey respondents stated that their entire family was evacuated; this includes those who evacuated either before or after the tsunami.

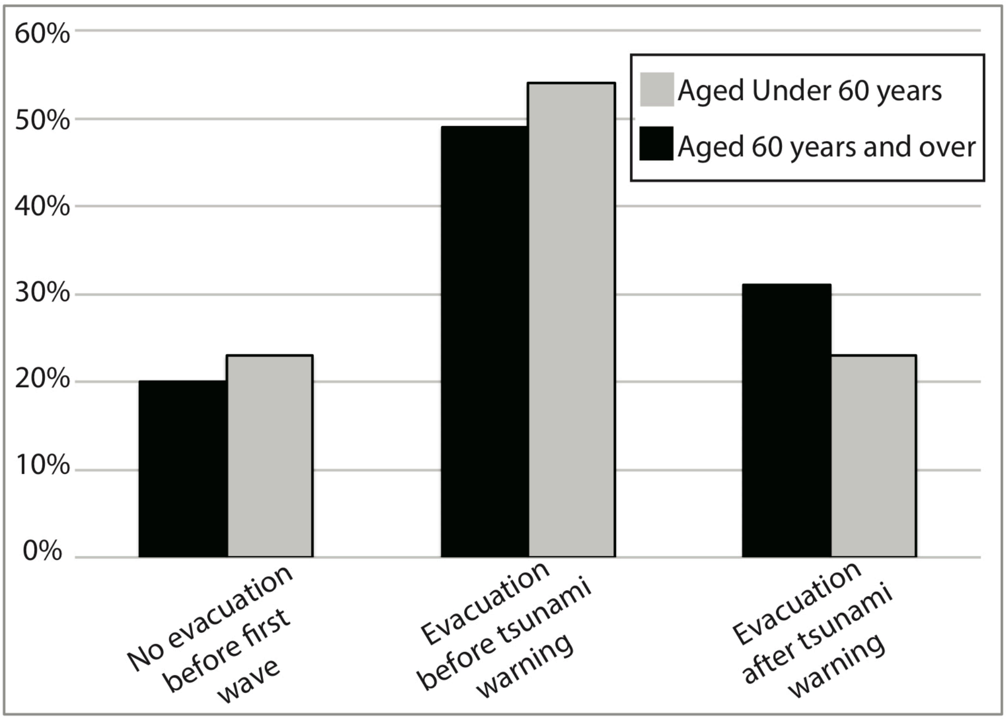

Figure 4: Graph illustrating relative timing of evacuation by age group. A marginally greater percentage of the elderly respondents evacuated prior to the arrival of the first wave than those below 60 years old.

50% of respondents stated they had no knowledge of a local evacuation plan at the time of the tsunami, and only 35% stated that they knew a plan was actively in place. Critiques of evacuation infrastructure and plans outlined by residents included a lack of sufficient roads to evacuation shelters resulting in traffic congestion (a problem also highlighted in other areas of the Tohoku region [see 36, 52]; a lack of water supply in evacuation zones; and a reduced focus of plans on individuals at the greatest risk. At group interviews many residents stated they had not been involved in evacuation drills prior to the event. A number of those who did know of evacuation plans highlighted that they were unaware what the shelter plans immediately following the evacuation were, or what disaster accommodation was available to them. This was reflected in the strong variance of accommodation reported in the days following the tsunami. Of 66 situations of temporary shelter in the immediacy of the disaster reported, only 25 respondents had one place of residence prior to moving into their current temporary home. Many residents listed two or more places of residence, with the maximum number of addresses recorded prior to current accommodation being 5 over a 7-month period.

3.3 Temporary housing

Among the elderly sample within temporary housing, the average number of residents per occupied unit stood at 3 persons, with the largest home providing for 6 people. Average occupancy rate across all sites surveyed was 91%. Occupancy percentages varied from 75% of the 233 units in Nagamachi to 100% of 23 units in Kesennuma's Akaiwa complex. The highest number of empty units at a single site was observed at Rikuzentakata, where approximately 150 of a possible 2,150 were uninhabited (93% occupancy). In spite of recommendations from previous studies into the elderly in THCs noting that a solitary environment can have serious physical and mental health consequences, ranging from solitary death to alcoholism and depression [see 5, 53], 7 of the 53 elderly respondents were living alone over 3 years after the disaster. The average age of the individuals living alone (73 years) was above the average for the sample (68 years). Furthermore, only 2 of the 7 respondents who listed single occupancy were in the Minamisanriku complex, where steps to prevent social isolation and 'lonely death' were an official strategy [see 54].

Regarding the physical structure of temporary homes, many residents expressed concern. In Sendai, residents in informal interviews felt that whilst the government had learned a number of lessons from previous events, such as Kobe, they had not been reflected in subsequent policy or applied broadly across THC strategy to be effective. A portion of residents criticised the size of temporary housing. Concerns were raised in particular that a lack of floor space compromised the ability to have storage and personal belongings: the average floor size estimated by the residents was $25.3m^2$. A lack of insulation in the initial design of structures at a number of complexes, specifically noted at Nagamachi, meant that a number of elderly residents in informal interviews criticised homes for their proclivity to heat loss due to the materials of their construction [24]. Thermal insulation was added at Nagamachi at a later date. Residents also cited a lack of soundproofing, particularly pertaining to noise in washrooms, which a number felt stressed their domestic relationships [24].

When asked about their intentions for the future, informal interviews of the elderly suggested that lower temporary residency periods might be preferred to waiting for what was deemed overly disaster-resistant permanent housing. Two residents stated that they were "too old for a disaster to affect them again". Furthermore, a belief that the elderly demographic was not a part of long-term plans was implied. In questions over permanent reconstruction, one respondent stated they had not attended a community planning meeting as they felt their age group was "too old" to have a valid opinion on the process. A number of residents still, however, expressed a wish to relocate to higher ground were they to move again, and a large number of residents (87.5%) had made longer-term plans regarding where they would wish to relocate.

4. Discussion

A number of factors can be used to investigate the efficacy of an Early Warning System (EWS) and temporary housing following a disaster. Herein we discuss the suitability for the elderly of the EWS and temporary housing of the 2011 Great East Japan Earthquake and Tsunami (GEJET) based on the written surveys and interviews conducted in 6 temporary housing complexes in Miyagi. In particular, we focus on: (1) Which methods of warning dissemination reached respondents and whether age was a distinguishing factor in this; (2) Whether such warnings were effective in prompting timely evacuation and how age may affect this; and (3) The degree of suitability of the prefabricated housing units in temporary housing complexes (THCs) for the local population which includes a high proportion of elderly people. We note that a restriction on any such study is that respondents were survivors: A lack of data for warning receipt among fatalities places a constraint on assessing the efficacy of warnings or evacuation practices for those who lost their lives.

The first test of the efficacy of an early warning system is the rate of receipt among the target population. In this study, the majority of respondents (81%) received a warning. There was a higher penetration of tsunami warnings, which came after the earthquake warnings, received amongst the elderly (60 years and over) than those under 60 years old. In itself, this suggests the adopted early warning methods were suitable and did not disadvantage the elderly population.

It is perhaps somewhat surprising that more technological approaches to warning dissemination did not disadvantage the elderly. Focussing on the most common type of warning received by respondents in our study - SMS and AMP messaging, the GEJET highlights the need for any technological approaches to be compatible with new technologies. In 2011 a number of overseas smart phone brands, of which younger generations are typically the greatest consumers, did not have software that supported SMS and AMP early warning capabilities for tsunamis (55). As such, their products were not eligible for components of Japan's 'Cell Broadcast' system [see 55]. One of these was Apple Inc., whose earlier models could receive earthquake notifications only for SMS/AMP, as opposed to both earthquake and tsunami alerts [56]. This resulted in those with older phones (more likely among the elderly) being more able to receive such warning messages through their phones. This raises the question of how a government can ensure new technologies do not make current early warning systems redundant.

Our results demonstrate the need for multiple warning types to be in place to allow for potential redundancy. Additionally, such warnings need to acknowledge local constraints in the natural and built environment. No one type of warning reached more than 40% of respondents and all but AMP tsunami warnings individually failed to reach more than 22% respondents. In accounting for non-receipt of warnings, residents cited the failure of national power relays in Kesennuma City; the deadening effect of topography on warning sirens in areas with high rates of primary labour (fishing & agriculture); and the influence of soundproofing in residences close to Sendai Airport. Slightly lower penetration rates were reported by a previous survey of 174 community members conducted by the Mitsubishi Research Institute on behalf of the Ministry of Internal and Communication (MIAC) [57]. Its findings stated that the municipality broadcast system for disaster management (MBSDM), which in our study is denoted as 'siren', was the most effective warning, reaching 26% of respondents [57]. This was followed, in order of dissemination efficacy, by television (25%), and radio warnings (24%) [57]. A 2011 Cabinet Office report also suggested that the siren/MBSDM system was the most effective method for disseminating warnings, however, a higher penetration of 52% of respondents was recorded, 45% of whom took evacuation action [58]. Therefore, although exact penetration rates and the relative success of different warning types differs between different studies, all three studies found that no one warning type reached more than 52% of those surveyed, and in a number of cases many different media had similar dissemination rates. This reinforces the assertion that multiple warnings are required to remediate against different geographical, socioeconomic, health or demographic variables among different municipalities, all of which play a role in media efficacy.

In accounting for differences in rates of notification between earthquake and tsunami warnings amongst the same demographics, it is important to note the potential influence of frailty, culture, disaster preparedness, and social capital upon behavior following a preliminary earthquake warning. 54% of respondents under 60 years old, and 49% of those over 60 years old stated that they evacuated or started to evacuate prior to the dissemination of a tsunami warning; presumably because they had already felt and responded to the earthquake shaking or the earthquake warning. This makes the content of pre-event disaster preparedness material all the more important, as those already in the process of evacuating may have been less likely to receive warning information or updates through exposure to fewer media.

Another test of the efficacy and suitability of a warning system is the degree to which it will instill a desire for evacuation [59]. Despite the elderly being more likely to evacuate later (either after receiving a tsunami warning or after the arrival of the first wave), there was a high degree of self-evacuation on the part of individuals both elderly and younger overall, particularly to areas of higher ground. This should be considered a success, as typically the elderly demographic holds a lower rate of evacuation in most disasters, particularly without coordinated assistance [60]. Furthermore, whilst other studies have found that links between disaster vulnerability and age often have caveats relating to social capital, income or physical health (see [60-62], a number of publications express concern over the ability of the elderly specifically to comprehend and understand hazard information and warnings regardless of secondary factors. This is primarily through the reduction in cognitive ability, and auditory and sensory perception of individuals as they age [see 13, 63, 64]. The high rate of warning receipt and evacuation in this study however, suggests that the content of both tsunami and earthquake warnings were clear and elicited the desired response among many of the elderly and younger. This is further supported by very few of the interviewees stating that they sought confirmation from their neighbors or friends prior to taking protective action; a factor that Mileti [8] describes as "milling". We suggest the sheer volume of warnings received by some individuals may have played a role in this.

To be successful, a warning system not only needs to reach intended recipients and prompt them to take action, but these people need to know where to go and what to do. However, over half of respondents were unaware of evacuation plans prior to the disaster and many had not participated in a drill; it was also highlighted by many that shelter plans following the event were unknown. Many residents evacuated by car, in spite of this being a practice that is specifically prohibited against by the Fire and Disaster Management Agency due to insufficient transport links to shelters in some municipalities at the time [38, 65]; some residents near Sendai airport specifically noted the long distance to the intended shelter being an issue for them. The lack of awareness of local plans and in some cases acting against official advice raises questions as to the suitability of localized disaster preparedness and pre-disaster hazard information to the elderly. It highlights a lack of communication as to 'best practice' evacuation methods beyond a 'move to high ground' methodology at a local level, and runs counter to many elderly disaster victims being unable to evacuate on foot [65]. Uncertainty regarding where to go and what to do both in the immediacy of the disaster and over the longer term regarding housing was raised as a concern by the residents, demonstrating the need for clear communications from official sources before during and following a disaster to help relieve anxiety.

The above raises broader questions as to whether factors such as the common difficulty of the most frail and vulnerable to self-evacuate, due to a relative inability to physically move to a safe space, may be greater factors in determining mortality and injury in disaster over warning receipt, warning notification comprehension and subsequent response.

In the aftermath of the GEJET, the JMA ran a review and revision of their early warning system capabilities and disaster preparedness [see 31, 65]. Whilst the review highlighted issues with message comprehension and content, including the incorrect reporting of wave heights and earthquake M_W in the immediacy of tsunami formation, it focused primarily on the need for message content to instill a desire for evacuation rather than how warnings may be better disseminated through various media [31]. Furthermore, whilst infrastructure regarding the detection of seismic waves and tsunami height forecasting was improved, and local pre-event disaster preparedness material has been improved and more widely distributed, few changes or recommendations have been made regarding infrastructure for warning dissemination on local and community scales (i.e. improving redundancy in grounded electricitydependent warning media or those requiring telecommunication reception) [31]. In light of this study's findings, and expanding upon improvements already implemented by the JMA, this paper puts forward a set of further recommendations that may aid future warning system media dissemination and disaster evacuation:

1. Adopt a bottom-up management approach, whereby consultation takes place at a community-level scale when selecting the most suitable warning media for specific regions – whilst it may be more economically viable, there is no single universally effective dissemination mechanism or evacuation technique on a national scale.
2. Acknowledge that there may not be one type of warning that is optimal for all residents or demographics and therefore consider multiple types of warning.
3. Recognize that future technologies may create incompatibilities with current warning dissemination.
4. Increase levels of potential redundancy, and therefore resilience within grounded electricity supplies to maintain full operability of warning systems (such sirens and telecommunications-dependent media) following a seismic event.
5. Brief and involve local communities in the planning, dissemination, and training exercises involved in evacuation plans and protocols to develop local knowledge and cultivate preparedness.

Disaster vulnerability extends beyond the immediate phase into the transitional phase of recovery. Temporary housing is a key part of what affects people's vulnerability during this time by affecting both their physical and mental health. Factors known to affect vulnerability to disasters in the context of temporary housing include age and social isolation, as was found following the 1995 Kobe earthquake [4, 25]. The high rate of elderly single residency recorded in this study (13%) suggests that individuals remain at risk in certain housing complexes despite recommendations arising from previous analogous events. Indeed, studies of mental and physical health amongst elderly temporary housing residents suggest that solitary environments may increase their likelihood of depression or malaise [5, 66]. In this study, the incidence of single residents in complexes where *kodokushi* (solitary and unnoticed death) management and prevention techniques were not confirmed as official programmes may have worked to further compound this risk. Having the majority of solitary elderly residents (5 of 7) living in complexes without these prevention measures may have arisen in either one of two ways. Elderly residents may have lived alone from the start of a disaster recovery process, and may have been designated to inappropriate THCs (those without kodokushi-prevention strategies) as a result of housing lottery-based allocation. Alternately, individuals may not initially have entered complexes as solitary residents, but over the course of their period of residency circumstances may have changed (loss of a family member, other household members returning to permanent accommodation etc.) resulting in them now living alone. A greater understanding as to the root cause of solitary living would facilitate improvements in housing allocation and the operability of *kodokushi*-prevention programmes, and this is an area where further research is required.

A lack of space highlighted by participants, in terms of both floor and personal storage, attests to inappropriate aspects of THC design, particularly in relation to long-term operability. Housing structures observed within this study neglect the possibility that as evacuees rebuild their lives, and re-purchase items that were lost as a result of the tsunami, they will accumulate more possessions if they hold a greater period of residency. Furthermore, homes within the sample failed to account for the return of individuals' social capital with time. With the re-establishment of social networks, residents may wish to entertain or organise visits by friends or family, and as the size of an individual's network increases they will require an increase in the amount of space available to them. Although the complexes visited did have common rooms in which the questionnaires and interviews were conducted, these are public rather than private spaces. If there is a chance that temporary housing may be required for multiple years in the wake of disaster, as has been the case in Tohoku, structure design needs to take these factors into account and ensure that the space allocated to individuals is be appropriate not just for the short-term (<1 year) phase of the recovery period, but for the entirety of its lifecycle.

A lack of insulation was cited as an issue within the Sendai region prior to retrofitting. With temperatures that can fall below 0°C during some months of the year, this placed a significant caveat on the suitability of housing in the shorter-term recovery phase. Whilst colder conditions could be seen as deleterious to all ages and demographics within housing complexes, the elderly are particularly indisposed to the potential side effects of the cold. Indeed, a number of studies point to a positive correlation between low temperature and ill health, with the incidence of strokes and myocardial infarction particularly prevalent among elderly individuals exposed to colder temperatures in their built environment [see 67, 68]. A lack of appropriate insulation by the Japanese Reconstruction Agency in the initial construction of homes, and the retro-fitting of insulation at a far increased cost, represents a considerable oversight, and it could be argued that an improved quality of housing in the first instance may have reduced the strain on prefectural healthcare systems in the months and years following the GEJET. This is of particular concern given that, according to a 2013 report by the Japanese Red Cross [69], 10% of THC residents were concerned for their health after holding residency in temporary housing complexes for less than two years, and in a number of affected prefectures, including Miyagi and Iwate, the earthquake and tsunami itself had already resulted in the considerable disruption of primary and secondary health care systems [see 70].

Whilst temporary housing units post-GEJET were allocated on a principle of supply and demand, informal interviews also raised concerns by the elderly over accommodation in the next phase of the recovery process. Both interviews and the survey questions highlighted that there was little interest from the elderly cohort of the study to have public housing that was particularly disaster resistant, as many felt they were "too old for a disaster to affect them again". Concerns were raised over the potential for further lottery allocation should any new accommodation become available in the future. This highlights the myriad of demographics and their respective opinions that may be involved in a disaster, and asks questions as to whether a 'one size fits all' methodology to post-disaster reconstruction is the best policy for disasters where a particularly vulnerable demographic has been so disproportionately affected over others.

5. Conclusions

This study presents an analysis of the efficacy of earthquake and tsunami early warning systems and temporary housing complexes in the context of the Japan's elderly population. Residents over the age of 60 years in Miyagi and Iwate temporary housing complexes were surveyed during a transitional phase of recovery, three years after the GEJET. Early Warning System alerts were received among the majority of those surveyed (81% earthquake and/or tsunami, 62% both earthquake and tsunami).

However, no one method of warning dissemination reached the majority of respondents. This reflects a need for multiple warning systems and media in order to remediate against differences in the geographical, socioeconomic or health variables between communities and their residents. Statistical analysis found that age was not the most significant factor in determining whether a warning was received, and a high rate of receipt across the sample implied that sufficient warning media were in place to inform both age groups surveyed. 80% and 77% of respondents aged ≥60 years and <60 years respectively evacuated prior to the tsunami's arrival. However, only 50% of respondents were aware of the evacuation plans, an unawareness of shelter plans following evacuation was highlighted, and many residents had not participated in evacuation drills. Furthermore, a lack of 'best practice' evacuation was also noted: whilst many individuals (even the elderly) observed the principle of *tsunami tendenko* – immediately moving to higher ground – many went against official guidelines and used their cars as a means of transport in this situation. This highlights the need for continuing education around evacuation arrangements and practice, and the need to develop alternative strategies to assist those who feel that they are not within walking distance of a shelter. Regarding temporary housing, the principal concerns of long-term residents included solitary living, size of units, lack of insulation (although this was later improved at some sites), and lack of soundproofing leading to limited privacy. Similarities with problems encountered in Kobe temporary homes raises questions as to whether construction or policy lessons have truly been learned. A number of elderly residents also expressed concern that their needs and requirements were not taken into account in planning for future permanent housing strategies. Rather than simply catering to the average citizen, or to 'minimum standards', THC design needs to understand the context and spatial distribution of vulnerability within the local communities it is designed to serve: in doing so it will be able to cater better to the most at risk groups and drive individual efforts at recovery.

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