SURVEY ON RESIDENTS' RESPONSE TO EARTHQUAKE EARLY WARNING DURING THE 2008 IWATE-MIYAGI INLAND EARTHQUAKE IN JAPAN

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ABSTRACT: When the 2008 Iwate-Miyagi Inland Earthquake occurred on July 14, 2008, earthquake early warning (EEW) was provided to regions where the intensity of shaking was expected to be greater than JMA 4. The warning was widely broadcast on television, radio, mobile phones and loudspeakers. In Shonai Town, Yamagata Prefecture, EEW information was broadcast over loudspeakers using the J-Alert system that transmits information by satellite. In this research, a questionnaire survey was conducted to understand residents' response to the warning. In the town, 800 questionnaires were distributed, and 591 responses were obtained. The results of the survey revealed that residents' understanding of the proper response to EEW was insufficient and it is necessary to enhance residents' capacity to take proper action when they receive a warning.

Key Words: earthquake early warning, the 2008 Iwate-Miyagi Inland Earthquake Times, questionnaire survey

INTRODUCTION

The Japan Meteorological Agency (JMA) began to provide the service of earthquake early warning (EEW) to the public on October 1, 2007. This is a new system that quickly analyses seismic wave data observed by seismographs near the epicenter and provides prompt alerts before the arrival of strong tremors (S-waves). This system aims to mitigate earthquake-related damage by allowing countermeasures such as enabling individuals to protect themselves quickly in various environments such as houses, offices and factories. A warning is widely broadcast on television, radio, mobile phones and loudspeakers.

The J-Alert system is another warning system in Japan launched in February 2007. It is a satellite-based system that allows authorities to broadcast alerts quickly to local media and directly to residents via a system of loudspeakers. Figure 1 shows the process whereby EEW information is transmitted by the J-Alert system. After the nearest seismometer observes the P-wave, seismic wave data is analyzed, and the focus, magnitude and intensity are estimated. After JMA announces EEW, the Fire and Disaster Management Agency (FDMA) transmits EEW to local government by satellite. At

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local government facilities, a loudspeaker system automatically boots and starts to broadcast EEW to residents. The FDMA operates the J-Alert system for the purpose of protecting citizens. Alerts include not only natural disasters such as tsunamis and earthquakes, but also military threats such as missiles and terrorist attacks. According to the newsletter of the FDMA, 43 out of 47 prefectures and 150 out of 1781 local governments have adopted the J-Alert system as of January 9, 2009. These numbers are expected to increase in the future as the FDMA is strongly promoting adoption of the J-Alert system.

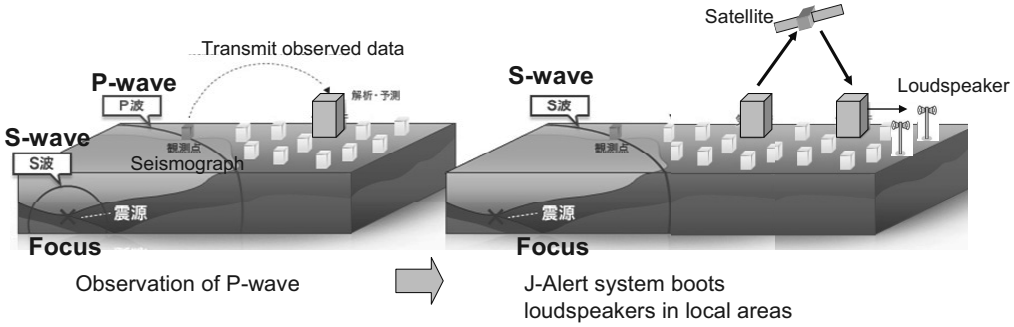

Figure 1. Transmission of EEW information by the J-Alert system

The Iwate-Miyagi Inland Earthquake occurred in the southern inland region of Iwate Prefecture, Japan at 8:43 JST on Saturday morning, June 14, 2008. The JMA magnitude was estimated to be Mj 7.2, and the maximum JMA intensity was measured as “6 lower” on the JMA intensity scale. According to the FDMA, 17 people died, 426 people were injured and 30 houses were completely destroyed. Immediately after the earthquake, EEW was provided to the regions where the intensity of shaking was expected to be greater than JMA 4. Figure 2 presents a map published by the JMA showing the epicenter of the earthquake and the lead time before the arrival of strong tremors. The yellow parts in Figure 2 denote the areas where EEW was broadcast. Unfortunately, the warning could not be provided before strong tremors in areas that were close to the focus of the earthquake. However, in several cities outside those areas, the lead time between the warning and the arrival of strong tremors was around 10-25 seconds, and residents were able to respond to the warning. It was the first earthquake since October 2007 for which EEW could be successfully broadcast before the arrival of strong tremors. The warning was widely broadcast on television, radio and mobile phones. In addition, the warning was broadcast to residents via loudspeakers using the J-Alert system in the regions where intensity was expected to be greater than JMA “5 upper”. This was the first broadcast of EEW using the J-Alert system, although the regions were limited to two cities and one town.

Shonai Town, Yamagata Prefecture was one of the regions where EEW was broadcast over loudspeakers using the J-Alert system. The location of the town is shown in Figure 2. In this research, a questionnaire survey was conducted in Shonai Town in order to understand residents’ response to the warning. The residents’ experience of receiving EEW by all the available means of communication including loudspeakers of the J-Alert system in Shonai Town is valuable for discussing improved use of EEW information.

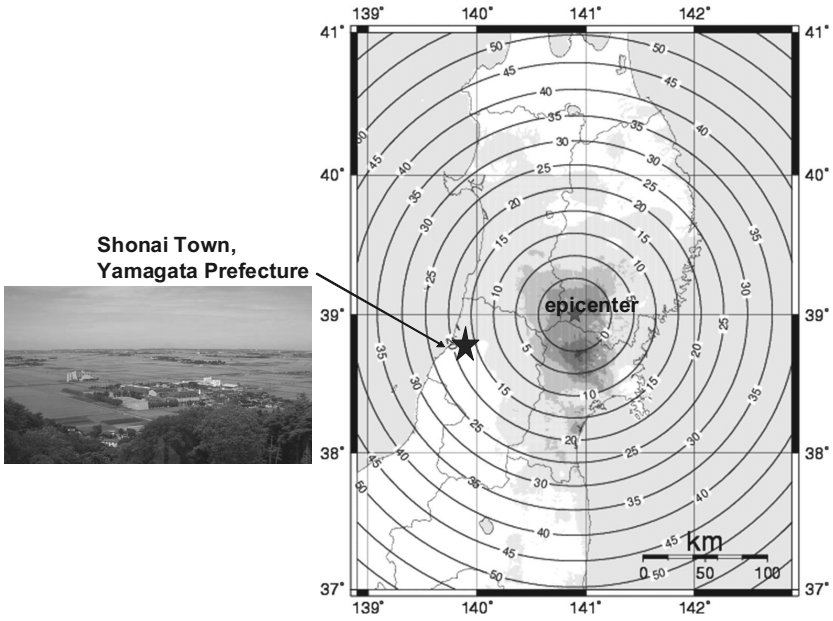

Figure 2. Epicenter and lead time between EEW and the arrival of strong tremors during the Iwate-Miyagi Inland Earthquake

PROCESS OF BROADCASTING OF EEW IN SHONAI TOWN

Shonai Town is a small town of 249.26 square kilometers with a population of 24,073. Shonai Town adopted the J-Alert system in April 2008. Two months later, the Iwate-Miyagi Inland Earthquake occurred. Before April, the town office explained the implementation of the J-Alert system to town leaders and announced it in the town news magazine in March.

The process of EEW broadcasting using the J-Alert system is shown in Table 1. The table shows the process used for two earthquakes: the Iwate-Miyagi Inland Earthquake at 8:43 JST on June 14 and another earthquake off the coast of Iwate Prefecture at 0:26 on July 24. At the time of the Iwate-Miyagi Inland Earthquake, EEW was broadcast to the public 10 seconds after the occurrence of the earthquake at the focus. After 1 second, the J-Alert system in Shonai Town office received an alert of shaking with intensity 4 from the FDMA by satellite. However, the J-Alert system did not boot because the criterion for booting the system was set at intensity “5 lower” or greater. At 28 seconds after the earthquake occurrence, the expected intensity increased to intensity “5 lower” and the J-Alert system booted. Finally, loudspeakers in Shonai Town began to announce EEW at 41 seconds after the earthquake occurrence, as preparation for broadcasting required 12 seconds.

Figure 2 shows the timing of EEW broadcasting at the time of the Iwate-Miyagi Inland Earthquake. First, chimes sounded (8 seconds) and then the warning stated “This is a large earthquake, this is a large earthquake” (6 seconds), on the basis of the seismic waves recorded by the nearest seismograph of Kyoshin-Net (seismograph network by the National Research Institute for Earth Science and Disaster Prevention (NIED)). As shown in Figure 1, the S-wave arrived at Shonai Town between the booting of the J-Alert System and the start of EEW broadcasting over loudspeakers. The warning by the J-Alert system failed to be broadcast before the arrival of S-wave; however, EEW was successfully broadcast to the public on television and radio.

Based on the lessons from the Iwate-Miyagi Inland Earthquake in June, the criterion for booting the J-Alert system was lowered to intensity 4, which is same criterion as EEW broadcasting for the public. At the time of the earthquake on July 24, the J-Alert System in Shonai Town office received an alert

from the FDMA by satellite 10 seconds after the occurrence of the earthquake at the focus. Loudspeakers in Shonai Town successfully began to announce EEW before the arrival of S-wave at 23 seconds after the occurrence of the earthquake. This was the first successful broadcast of EEW by the J-Alert system before the arrival of strong tremors since the J-Alert system launched in Japan. In this case, the change of the criterion for broadcasting to intensity 4 led to early information propagation. In order to increase the likelihood of successful warnings before strong tremors in the future, improvement of both the EEW system and the J-Alert system is necessary. In particular, decreasing the boot time and increasing the number of local governments that adopt the J-Alert system are essential.

Table 1. Process of broadcasting of EEW for two earthquakes

	June 14			July 24		
	Time	Elapsed time(s)	Elapsed time after P-wave in Shonai (s)	Time	Elapsed time(s)	Elapsed time after P-wave in Shonai (s)
Earthquake occurrence at focus	8:43:45	0	−19	0:26:35	0	−16
EEW broadcasting to the public	8:43:55	10	−9	0:26:56	21	5
Alert of intensity 4 from FDMA	8:43:56	11	−8	0:26:45	10	−6
Arrival of P wave at Shonai Town	8:44:04	19	0	0:26:51	16	0
Alert of intensity 5 lower from FDMA	8:44:13	28	9			
Boot of J-Alert system	8:44:14	29	10	0:26:48	13	−3
Start of EEW broadcasting over loudspeakers	8:44:26	41	22	0:26:58	23	7

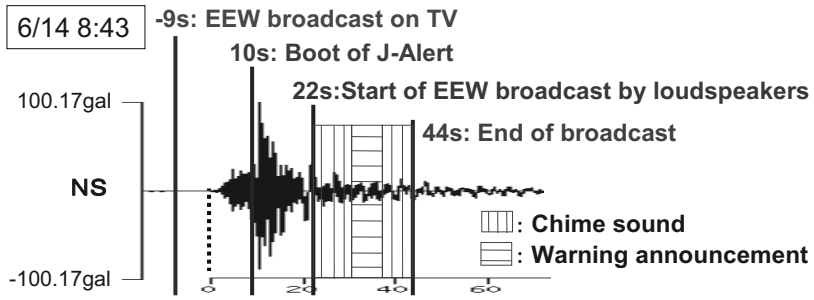

Figure 3. Timing of EEW broadcasting during earthquake on June 14

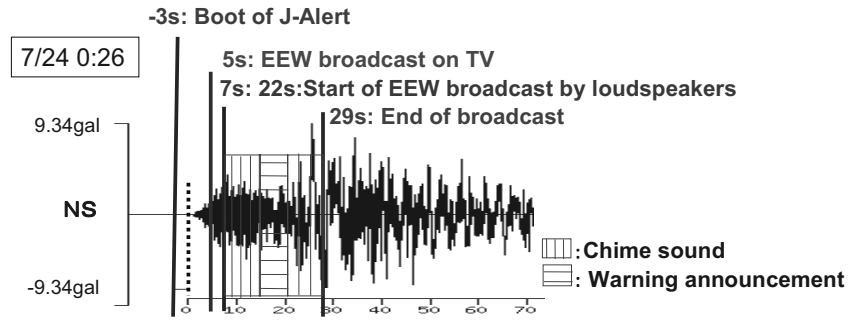

Figure 4. Timing of EEW broadcasting during earthquake on July 24

OUTLINE OF QUESTIONNAIRE SURVEY

In order to understand the residents' response to the warning, a questionnaire survey of residents was conducted in Shonai Town with the cooperation with Shonai Town local government. In October 2008, 800 questionnaires were distributed in the town and 591 responses were obtained.

Characteristics of Respondents

Among the 591 respondents, 57.2% of the respondents are male and 42.8% are female. The distribution of respondents' age is shown in Figure 5. Half of the respondents are more than 60 years old. Respectively, 79.9%, 16.3% and 1.8% of the respondents live in two-story single-family timber houses, one-story single-family timber houses and timber apartments. Furthermore, 13.7% of the respondents have an elderly family member who cannot walk without assistance, and 7.8% of the respondents have infants and 23.6% have children in kindergarten or elementary school.

Figure 6 shows the number of respondents who experienced past disasters such as the 1964 Niigata Earthquake or the 1983 Nihonkai-Chubu Earthquake. Regarding the respondents' anxieties over disasters, anxiety over earthquakes is the highest, surpassing that for heavy rains, floods, landslides and strong winds. About 70% of the respondents have strong anxiety and 25% have slight anxiety over earthquakes.

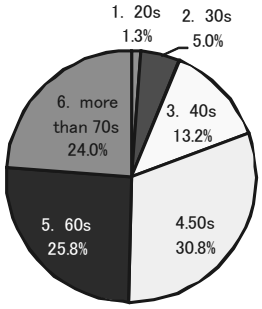

Figure 5. Respondents' age

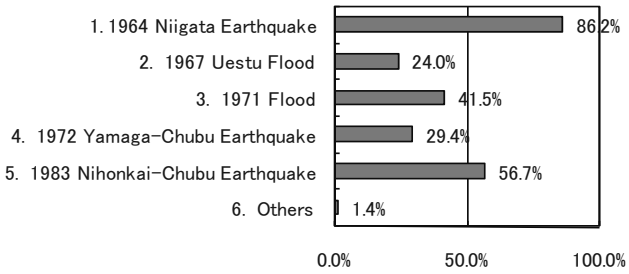

Figure 6. Respondents who experienced past disasters

Respondents' Knowledge of EEW

Next, respondents' knowledge of EEW and its broadcasting were investigated. Figure 7 shows the results regarding their knowledge of EEW before both earthquakes. Among the

respondents, 48.7% knew both the name of EEW and that it forecast a strong tremor just before its arrival. However, 33.4% knew only the name of EEW and 17.9% knew neither its name nor its meaning. When the Iwate-Miyagi Inland Earthquake occurred in June 2008, almost seven months had passed since the system's implementation. The low percentage of the respondents who fully understood the meaning of EEW before the earthquakes indicates the necessity of increasing residents' knowledge of EEW.
Figure 8 shows the results regarding the respondents' knowledge of methods of EEW broadcasting before both earthquakes. Among the respondents, 27.3% knew of broadcasting on both television and loudspeakers, 43.1% knew of broadcasting only on TV, and 12.9% knew of broadcasting only on loudspeakers. The percentage of respondents who knew of EEW broadcasting on loudspeakers was less than half. The reason for this might be that the J-Alert System was installed in Shonai Town just two months before the earthquake in June. The government of Shonai Town should make a continuing effort to improve residents' understanding of the methods of EEW broadcasting.

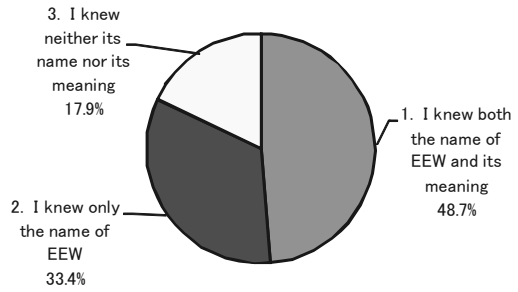

Figure 7. Respondents' knowledge of EEW before earthquakes

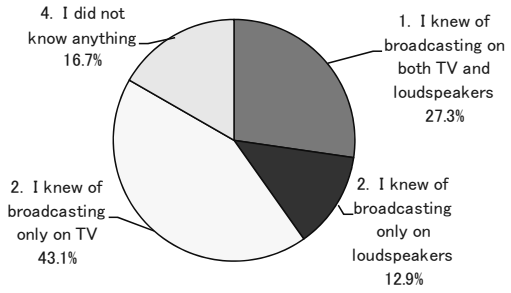

Figure 8. Respondents' knowledge of EEW broadcasting methods before earthquakes

RESIDENTS ALERTED BY EARTHQUAKE EARLY WARNING

Here, the residents' activities when EEW was broadcast were investigated. Figure 9 shows at the location of respondents at the time of the two earthquakes. When the Iwate-Miyagi Inland Earthquake occurred on a Saturday morning, 65% of the respondents were at home. At that time, 30% of the respondents were watching television, and 40% were working at the office or at home. When the other earthquake occurred after midnight in July, 79% were at home, which was higher than in June. At that

time, 63% of the respondents were sleeping and 16% were watching TV. Only 9% were working at the office or at home.
Tables 2 and 3 show how residents were alerted to EEW for each earthquake. For the earthquake in June, 63.9% heard EEW broadcast on loudspeakers. Compared with the 31.2% who saw EEW on TV, the number of respondents who heard EEW over loudspeakers was larger. This suggests that loudspeakers can effectively convey EEW information to a large number of residents. On the other hand, television can provide EEW information only if turned on. For the earthquake in July, the percentage of the residents who were alerted by loudspeakers was larger as it was after midnight. Figure 10 shows how clearly residents heard EEW for each earthquake.

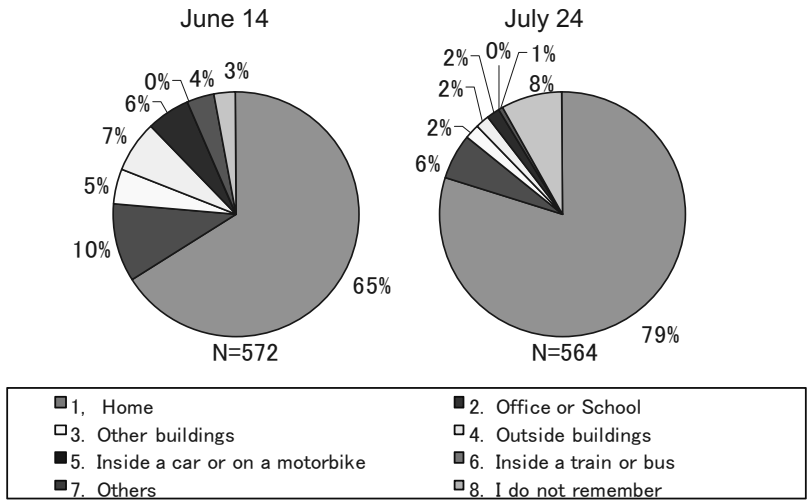

Figure 9. Location of respondents during the two earthquakes

Table 2. Residents alerted to EEW on June 14

		I saw on TV		
		Yes	No	Sum
I heard over loudspeakers	Yes	128	212	340
		24.1%	39.8%	63.9%
	No	38	154	192
		7.1%	28.9%	36.1%
	Sum	166	366	532
		31.2%	68.8%	100%

Table 3. Residents alerted to EEW on July 24

		I saw on TV		
		Yes	No	Sum
I heard over loudspeakers	Yes	56	216	272
		10.5%	40.6%	51.1%
	No	33	229	262
		6.2%	43.0%	49.2%
	Sum	89	445	532
		16.7%	83.6%	100%

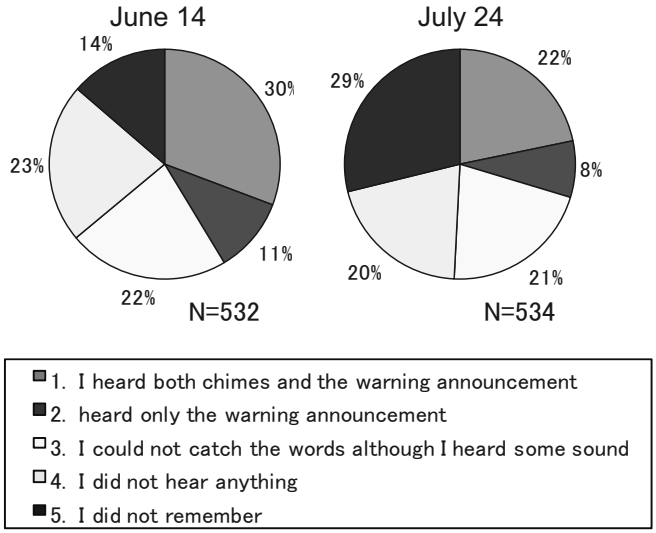

Figure 10. How clearly residents at various locations heard EEW over loudspeakers

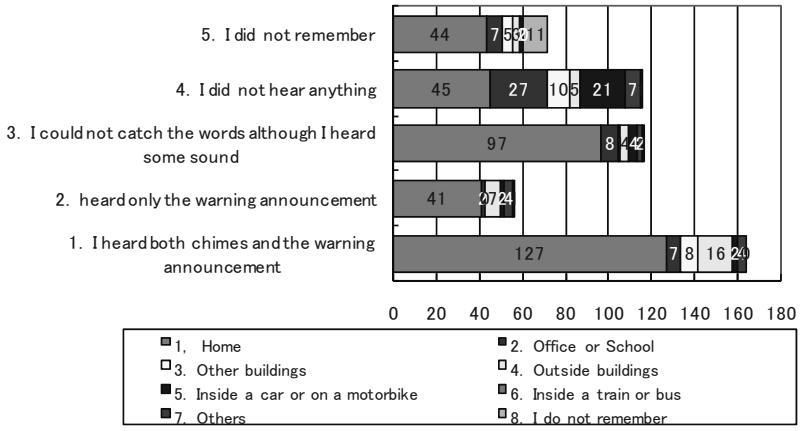

Figure 11. Relation between hearing EEW over loudspeakers and respondents' activities at the time of the earthquake in June

For the earthquake in June, 30% heard both chimes and the warning stating, "Large earthquake", while 11% heard only the warning stating, "Large earthquake". Moreover, 22% could not catch the words although they heard sound from loudspeakers, 23% did not hear anything, and 14% did not remember. For the earthquake in July, the number of the residents who did not remember was larger than in June, as more people were sleeping after midnight.

Figure 11 shows the relation between receiving EEW and the activities of residents for the earthquake in June. Among the 164 respondents who heard both chimes and the warning announcement, 86.6% were at home. On the other hand, among the 116 respondents who did not hear anything, 39% were at home, 23% were in their office or school, and 18% were driving a car or motorbike. This shows that EEW can be difficult to notice when people are in the middle of working inside a building or driving.

RESIDENTS' RESPONSE TO EARTHQUAKE EARLY WARNING

Response to Earthquake Early Warning During the Earthquake in July

Next, the residents' response to EEW was investigated. Here, we focused on the response to EEW in July because the EEW in June failed to be broadcast before the arrival of strong tremors as shown in Figure 3.

Figure 12 shows what respondents did immediately after hearing EEW. Blue parts correspond to the 157 respondents who heard chime sound or the warning words. Red parts correspond to the 214 respondents who could not catch the words although they heard some sound from loudspeakers and residents who did not hear anything. Most of the respondents tried to get earthquake information from television or radio, regardless of whether they heard EEW or not. About 40% waited and about 25% informed their children or people near them of the EEW. The aim of EEW service is to enable residents to quickly protect themselves before the arrival of strong tremors. However, very few residents tried to protect their bodies, or protect their children and elderly family members. This indicates that their understanding of the meaning of EEW and their capacity to take appropriate action were insufficient.

Between the two types of respondents, the difference of their response was verified by the chi-square method. Asterisks (*) in Figure 12 denote responses that differed with statistical significance according to the chi-square test. For respondents who heard EEW, the responses of "I tried to get earthquake information from television or radio", "I do not remember", "I opened the door or window" and "I went outside the house or building" increased compared with respondents who did not hear EEW. It is thought that these responses were promoted by hearing EEW. However, actions such as "I opened the door or window" and "I went outside the house or building" can lead to the possibilities of secondary casualties. Instead of these responses, actions such as "I protected my body" or "I informed children or people near them of EEW" should be promoted by hearing EEW. From these results, it can be seen that education of the public on appropriate responses to EEW is necessary.

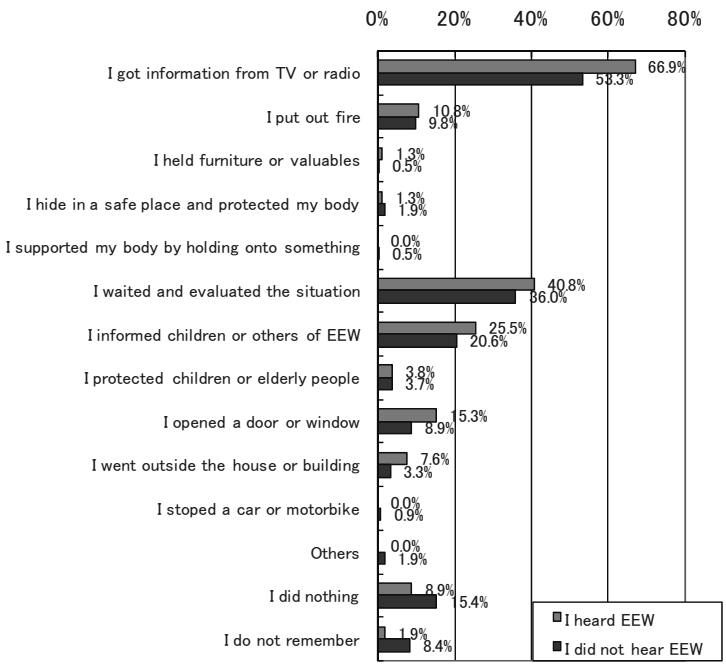

Figure 12. Actions after hearing EEW

Response to Future Earthquake Early Warning y

Finally, respondents were asked about what they would do if another earthquake the same as the Iwate-Miyagi Inland Earthquake were to occur and they were to receive EEW 10-20 seconds before the arrival of strong tremors. Figure 13 shows their responses. Among the respondents, 79% answered that they would put out fire. This was higher than the response of "I will get earthquake information by television or radio". It is understood that few respondents gave the response of putting out fire as the earthquake in July occurred after midnight. Now in Japan, the gas system usually has an automatic shut-down system in case of an earthquake. Considering that the safety of residents is the first priority, it is not necessary to put out fire immediately after an earthquake because these actions might cause secondary casualties. A high percentage of residents indicating that they would put out fire means that residents do not understand the current gas system. The percentage that responded "I will hide in safe place and protect my body" was 47% and fourth largest. Compared with its low percentage in Figure 12, it can be said that residents understood the necessity of protecting their bodies, although they did not actually respond to EEW in this manner.

In order to understand the difference in the answers in regard to sex, age, experience of past earthquakes, anxiety over earthquakes and the presence of family members who need help in the case of an earthquake, chi-square tests were carried out. Table 4 shows the p-value from the chi-square test in each case. Pink, orange and yellow parts were verified to be statistically significant with a probability of 5%, 1% and 0%, respectively. The response "I will put out fire" increased among residents who had experienced past earthquakes. Their past earthquake experience might cause misunderstanding, even though the current gas system does not require putting out fire due to the automatic shut-down system. The answer "I will hide in a safe place and protect my body" increased for young respondents. The response "I will inform children or people near me of earthquake occurrence" increased for females or respondents who have anxiety over earthquakes. It decreased for respondents who were more than 70 years old. The response "I will protect children, elderly and sick people" increased for those with infants, small children or elderly family members who cannot walk without assistance. The response "I will open a door or window" increased in the case of female respondents. No difference was observed for the response "I will hold furniture or valuables in order to prevent them from falling down", "I will support my body by holding onto something", and "I will stop a car or motorbike". Potential trends of responding EEW differed according to the characteristics of the respondents.

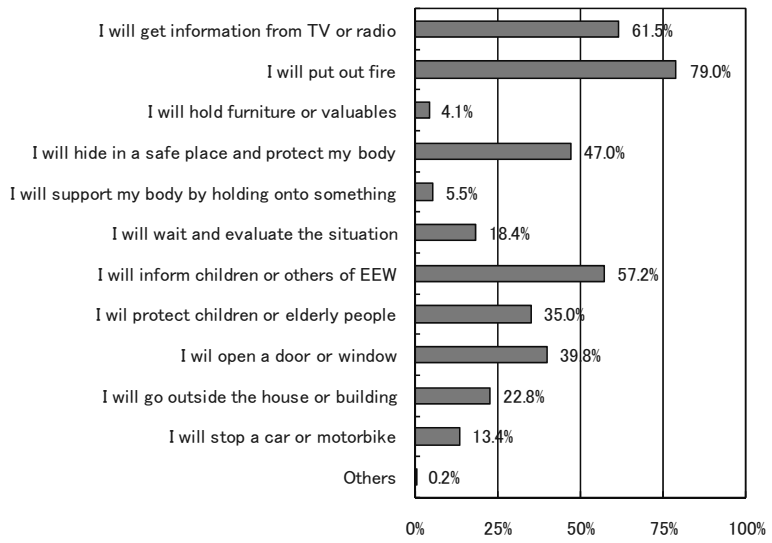

Figure 13. Response to future EEW

Table 4. Relation between characteristics of residents and planned response to future EEW

Response to future EEW	Sex	Age	Experience of past disasters	Anxiety over earthquakes	Presence of family members who need assistance
Get information from TV or radio	.933	.003		.378	.173
Put out fire	.418	.103	.000	.315	.023
Hold onto furniture or valuables	.220	.464	.846	.780	.813
Hide in safe place and protect body	.023	.000	.005	.006	.001
Support my body	.663	.063	.377	.223	.082
Wait and evaluate the situation	.013	.440	.116	.410	.416
Inform children or others of EEW	.000	.000	.028	.001	.008
Protect children or elderly people	.355	.002	.094	.281	.000
Open door or window	.000	.695	.021	.385	.050
Go outside house orbuilding	.112	.567	.534	.287	.433
Stop a car or motorbike	.222	.178	.660	.620	.897

CONCLUSIONS

The 2008 Iwate-Miyagi Inland Earthquake was the first earthquake since October 2007 for which EEW could be broadcast before the arrival of strong tremors. Shonai Town, Yamagata Prefecture was one of the regions where EEW was broadcast over loudspeakers using the J-Alert system. In this research, a questionnaire survey was conducted in Shonai Town in order to understand the residents' response to the warning. In October 2008, 800 questionnaires were distributed in the town and 591 responses were obtained.

Regarding residents' knowledge on EEW, only 48.7% knew both the name of EEW and its meaning. The percentage of the respondents who were aware of EEW broadcasting over loudspeakers was less than half. These low percentages suggest the necessity of increasing EEW knowledge among residents. In the case of the earthquake in June, 63.9% heard EEW broadcast over loudspeakers. Among the respondents who did not hear anything, 39% were at home, 23% were in their office or school, and 18% were driving a car or motorbike. EEW can be difficult to catch when people are in the middle of working inside a buildings or driving.

When we focus on the response to EEW in July, we found most respondents tried to get earthquake information from television or radio. Very few residents tried to protect their bodies, or protect their children and elderly family members. This indicates that their understanding of the meaning of EEW and their capacity to respond appropriately were insufficient. On the other hand, when the planned response to future EEW was investigated, 79% of the respondents answered that they would put out fire. This percentage increased among those who experienced past earthquakes. The high percentage of respondents who would put out fire means that residents do not understand the current gas system, because it is not necessary to put out fire owing to the automatic shut-down system.

From chi-square tests on the future response by respondents' characteristics, several differences were statistically verified according to their sex, age, experience of past earthquakes, anxiety over earthquakes and the presence of family members who need help in case of an earthquake. In order to enable residents to take proper action in response to future EEW, education on proper actions for various situations should be provided considering the trends in the responses observed in this survey.

In future work, we will continue questionnaire surveys for other EEW examples and accumulate data on human behavior in response to EEW. Based on these results, education material for increasing the capacity of residents to respond EEW will be developed.

ACKNOWLEDGMENT

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