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Article

Longitudinal associations of radiation risk perceptions and mental health among non-evacuee residents of Fukushima prefecture seven years after the nuclear power plant disaster

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ABSTRACT

We aimed to explore the effects of prolonged radiation risk perceptions on mental health after the Fukushima nuclear power plant accident occurred in 2011. We investigated the longitudinal associations of radiation risk perceptions five years after the accident with psychological distress and posttraumatic stress symptoms two years later among non-evacuee community residents of Fukushima prefecture. A two-wave questionnaire survey was administered for 4,900 randomly sampled residents in 49 municipalities of Fukushima prefecture excluding the evacuation area designated by the Japanese government. Radiation risk perceptions were assessed with a seven-item scale. Psychological distress and posttraumatic stress symptoms were measured by the K6 and the six-item abbreviated version of the Posttraumatic Stress Disorder Checklist-Specific version, respectively. We investigated the associations of radiation risk perceptions in the first survey conducted in 2016 with psychological distress and posttraumatic stress symptoms in the follow-up survey conducted in 2017–18, controlling for the baseline level of distress or symptoms using multivariate logistic regression analyses. Valid responses were obtained from 1,148 residents (23.4%). Higher risk perceptions of radiation exposure in the first survey predicted later post-traumatic stress symptoms but not psychological distress after controlling for baseline symptoms or distress. High risk perceptions of radiation exposure after nuclear power plant accidents can lead to posttraumatic stress symptoms.

1. Introduction

The Fukushima Dai'ichi Nuclear Power Plant accident occurred in March 2011 on the heels of the Great East Japan Earthquake, disrupting many residents' lives in Fukushima prefecture. The area within a 20 km radius of the power plant was designated as an evacuation zone by the Japanese government, and about 150,000 residents were forced to evacuate. Many residents outside the designated zone also evacuated spontaneously. Their evacuations have been prolonged, with approximately 71,000 continuing as evacuees seven years later (Reconstruction Agency, 2018). Those living in Fukushima prefecture also experienced a significant earthquake and tsunami. The number of individuals who died and who were reported missing in Fukushima prefecture because of the Great East Japan Earthquake was 1,614 and 196, respectively. Additionally, the number of completely and partially destroyed houses was 15,224 and 80,803, respectively (National Police Agency, 2018).

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Studies conducted after previous nuclear power plant accidents in Three Mile Island (TMI) and Chernobyl showed that the nuclear power plant accidents had long-term adverse effects on mental health of residents of the affected communities (Bromet, 2014; Bromet, Havenaar, & Guey, 2011). While, of course, people who were forced to evacuate from areas close to a nuclear power plant after the accident were severely affected, people living in a wide range of neighborhood communities were also affected. Non-evacuee community residents also showed increased concerns of adverse effects of radiation exposure on their health for several years (Ginzburg, 1993; Goldsteen & Schorr, 1982). Associations of concerns for adverse health effects of radiation exposure with psychological distress (Adams, Guey, Gluzman, & Bromet, 2011; Dew & Bromet, 1993; Goldsteen, Schorr, & Goldsteen, 1989), depression (Adams et al., 2011), anxiety symptoms (Bromet & Litcher-Kelly, 2002), posttraumatic stress symptoms (Adams et al., 2011), and poor self-rated health (Bromet, Gluzman, Schwartz, & Goldgaber, 2002) were reported six months to 19 years after the TMI or Chernobyl accidents. It is possible that enduring perceptions that radiation's adverse health effects may emerge later are so stressful that they could adversely affect residents' mental health or impede their recovery. For the Fukushima Dai'ichi nuclear power plant accident, a qualitative survey found that community residents living outside the evacuation zone also expressed concerns about radiation-related health risks (Karz, Reichstein, Yanagisawa, & Katz, 2014). A cross-sectional study reported that radiation anxiety and psychological distress were inter-correlated in non-evacuee community residents in Fukushima prefecture several years after the accident (Fukasawa et al., 2017), as in evacuees (Miura et al., 2017; Oe et al., 2016; Suzuki et al., 2015). A similar cross-sectional finding was reported from communities outside Fukushima prefecture (Niitsu et al., 2014). Compared to evacuees, the degree of risk perceptions of radiation exposure and its impact on poor mental health may be smaller among non-evacuee community residents, as they lived relatively remotely from the nuclear power plant. However, because the population size of neighborhood communities is much larger and heightened risk perceptions for radiation exposure could persist for years, the possible net impact of radiation risk perceptions among non-evacuees is non-negligible.

From the perspectives of prevention of long-lasting mental health problems following a nuclear power plant accident, it is important to examine the role of radiation risk perceptions in prolonged recovery from post-accident poor mental health. However, most studies examining these associations have used cross-sectional designs (Adams et al., 2011; Bromet et al., 2002; Bromet & Litcher-Kelly, 2002; Fukasawa et al., 2017; Niitsu et al., 2014; Suzuki et al., 2015). Only a few longitudinal studies have been conducted to address prospective associations of risk perceptions with mental health. However, the findings have not been consistent. After the TMI accident, Goldsteen et al. (1989) found an association between individuals' perceived harm to health six months after the accident and psychological distress three years later. In contrast, Dew, Bromet, and Schulberg (1987) reported no significant association between the perception of dangerousness of TMI assessed nine months after the accident and psychological distress assessed 30 months and 42 months after the accident. However, their follow-up study revealed a significant prospective association between the perception of dangerousness at nine months and psychological distress over the subsequent 10 years (Dew & Bromet, 1993). After the Fukushima accident, in a two-wave study of evacuees, Miura et al. (2017) revealed that risk perceptions of delayed effects and genetic effects of radiation exposure 10 months after the accident (wave 1) did not predict psychological distress at two years after the accident (wave 2). However, another longitudinal study of evacuees focusing on posttraumatic stress symptoms reported a positive association between radiation risk perceptions at 10 months and posttraumatic stress symptoms three years following the evacuation (Oe et al., 2017).

One of the reasons for inconsistencies among the previous longitudinal studies may derive from the outcomes used. Some risk factors for posttraumatic stress symptoms, which are event-related symptoms, and for depression or psychological distress, which are non-event-related symptoms, are suggested to be different in several studies conducted after a disaster among community residents (Cénat & Derivois, 2014; Gigantesco et al., 2013; Guo, He, Qu, Wang, & Liu, 2017; Labarda & Chan, 2018; Pietrzak, Southwick, Tracy, Galea, & Norris, 2012; Tracy, Norris, & Galea, 2011). This may be partly based on different cognitive vulnerabilities that contribute to the development of different psychological symptoms (Riskind & Alloy, 2006). Cognitive vulnerabilities are closely related to information processing biases (Elwood, Hahn, Olatunji, & Williams, 2009; Riskind, 1997; Riskind & Alloy, 2006; Riskind et al., 2000), which could affect the processing of information on radiation's adverse effects. Therefore, the relationships of radiation risk perceptions might not be the same with posttraumatic stress symptoms and depression or psychological distress. Lack of consistent findings in previous longitudinal studies after nuclear power plant accidents requires more evidence on these associations.

Thus, in the current study, we assessed both psychological distress and posttraumatic stress symptoms as indicators of mental health status and examined the temporal associations between radiation risk perceptions and these two outcomes using longitudinal data. We aimed to examine the contribution of radiation risk perceptions to the persistence of psychological distress and posttraumatic stress symptoms seven years after the nuclear power plant accident in non-evacuee community residents in Fukushima prefecture. We tested two hypotheses: (1) people with higher risk perceptions of radiation exposure five years after the accident are more likely to have psychological distress and posttraumatic stress symptoms two years later; and (2) the effects of radiation risk perceptions on later psychological distress and posttraumatic stress symptoms are independent from initial psychological distress or posttraumatic stress symptoms.

2. Material and methods

2.1. Study design and study population

Data were derived from two questionnaire surveys administered in 49 of the 59 municipalities of Fukushima prefecture, excluding the restricted areas close to the nuclear power plant designated by the Japanese government. The first survey was conducted from February to April 2016, five years after the accident. The details of the first survey were reported previously (Fukasawa et al., 2017). One hundred residents aged 20–80 years old were randomly sampled from each municipality based on the residence registry, with double weighting for residents aged 20–39 years old. From a total of 4,900 subjects, responses were obtained from 2,038 individuals. The second survey was conducted from November 2017 to January 2018, about seven years after the accident or 21 months after the first survey. The questionnaire was sent to 2,037 respondents in the first survey, excluding one respondent whose address information was not available.

2.2. Study variables

2.2.1. Psychological distress

Psychological distress was assessed using the K6, a 6-item self-administered standardized screening instrument of non-specific psychological distress during the past 30 days (Furukawa et al., 2008; Kessler et al., 2002). Items are rated on a 5-point Likert scale from 0 (none) to 4 (all the time), with a total score ranging from 0 to 24. Higher scores indicate higher distress. When individuals answered at least three items, their total scores were calculated by supplementing missing scores with the mean of the other items. The score in the second survey was dichotomized with a cut-off point of 5 based on a previous study (Sakurai, Nishi, Kondo, Yanagida, & Kawakami, 2011) and used as an outcome. To confirm the results, we repeated the analyses using a cut-off point of 13 instead of 5, which is also a cut-off point frequently

used in previous studies (Kessler et al., 2003; Miura et al., 2017; Oe et al., 2016; Suzuki et al., 2015; Yabe et al., 2014). The score in the first survey was used as a continuous variable to control for the baseline level of psychological distress.

2.2.2. Posttraumatic stress symptoms

Posttraumatic stress symptoms were assessed using the 6-item abbreviated version of the Posttraumatic Stress Disorder Checklist-Specific version (PCL-S) developed by Lang and Stein (2005). The PCL-S is a widely used questionnaire for people who have experienced a specific traumatic event (McDonald & Calhoun, 2010; Suzuki et al., 2017; Wilkins, Lang, & Norman, 2011). In this study, as the traumatic event, we specified the experience of the Great East Japan Earthquake, including the earthquake, tsunami, and nuclear power plant accident. The items, which measure the degree to which respondents are bothered by symptoms, are rated on a 5-point Likert scale from 1 (not at all) to 5 (extremely), with a total score ranging from 6 to 30. Higher scores indicate more severe symptoms. When individuals answered at least three items, their total scores were calculated by supplementing missing scores with the mean of the other items. The score in the second survey was dichotomized with a cut-off point of 17 based on a previous study (Suzuki et al., 2017) and used as an outcome. The score in the first survey was used as a continuous variable to control for the baseline level of posttraumatic stress symptoms.

2.2.3. Radiation risk perceptions

We defined radiation risk perceptions as negative cognitions, perceptions, and experiences, such as health concerns and stigma experiences, due to the exposure to the nuclear power plant accident. Radiation risk perceptions were assessed using the 7-item Radiation Anxiety Scale developed by Umeda et al. (Kawakami, 2013; Umeda et al., 2014). The details of this scale were reported previously (Fukasawa et al., 2017). The items were rated on a 4-point Likert scale from 1 (strongly disagree) to 4 (strongly agree), and the items' scores are summed to obtain a total score, ranging from 7 to 28, with a higher score indicating higher risk perceptions of radiation exposure. When individuals answered at least four items, their total scores were calculated by supplementing their missing scores with the mean of the other items. We used the score obtained at the first survey (Cronbach's alpha coefficient 0.84). Because two items of this scale include the word "anxiety," which could serve to magnify the associations of the risk perception measure with our outcomes, we repeated the analyses using a 5-item composite that omitted these items (Cronbach's alpha coefficient 0.79).

2.2.4. Socio-demographic characteristics

The socio-demographic characteristics included in this study were age, sex, educational attainment, household income in the past year, marital status, number of members living in the household, living arrangement, physical disease under treatment, and residential area assessed at the first survey. Household income in the past year was adjusted by the number of household members and categorized into high, medium, and low income groups (Fukasawa et al., 2017). Residential area of Fukushima prefecture was divided into eastern coastal (Hama-dori), central (Naka-dori), and western areas (Aizu).

2.2.5. Disaster-related experiences

To control for the damage and stressful experiences caused by the Great East Japan Earthquake, which have been consistently reported to affect post-disaster mental health (Goldmann & Galea, 2014; Norris & Elrod, 2006; Norris, Friedman, & Watson, 2002; Norris, Friedman, Watson, Byrne et al., 2002), we assessed two dimensions of disaster-related experiences in the first survey: direct damage and disaster-related family problems. To assess direct damage, four experiences were assessed: 1) harm to oneself; 2) harm to or death of family members; 3) loss of job or temporary absence from work; and 4) house damage or loss of property. To assess disaster-related family problems, two experiences were assessed: 1) deterioration of family relationships and 2) family separation. We calculated the number of damage incidents or family problems experienced in each category.

2.2.6. Social network

To control for individual social networks which are related to post-disaster mental health (Goldmann & Galea, 2014; Norris, Friedman, Watson, Byrne, et al., 2002; Norris, Friedman, & Watson, 2002; Norris & Elrod, 2006), the total score of the abbreviated version of the Lubben Social Network Scale (LSNS-6) (Kurimoto et al., 2011; Lubben et al., 2006) was used. The LSNS-6 consists of six items, including three items evaluating family ties and three items evaluating non-family ties. Items are rated on a 6-point scale from 0 to 5, with a total score ranging from 0 to 30. A higher score indicates a larger network. In addition, membership in a group was assessed using a list of 13 types of groups or organizations, such as neighborhood community associations, hobby groups, industry organizations, and religious groups. Respondents who were members of at least one of these groups or organizations were designated as belonging to some groups. We assessed these two indicators of individual social networks during the first survey.

2.3. Statistical analysis

First, we calculated descriptive statistics for socio-demographic characteristics, disaster-related experiences, and social network characteristics of the study subjects and their radiation risk perceptions, psychological distress, and posttraumatic stress symptoms in the first survey. Then we compared these basic characteristics of our study subjects with those of the individuals who participated in the first survey but who were not included in this study because of non-participation in the second survey or having missing information.

Second, we examined the relationships of individual socio-demographic, disaster-related, and social network characteristics, and radiation risk perceptions, psychological distress, and posttraumatic stress symptoms in the first survey with psychological distress and posttraumatic stress symptoms in the second survey. We compared these individual characteristics and radiation risk perceptions, psychological distress, and posttraumatic stress symptoms assessed in the first survey between those who scored above and below each cut-off point on the scale measuring psychological distress and posttraumatic stress symptoms in the second survey using chi-square tests or t-tests.

Next, we used multivariate logistic regression analyses to examine the associations of radiation risk perceptions in the first survey with psychological distress and posttraumatic stress symptoms in the second survey separately, controlling for the socio-demographic, disaster-related, and social network characteristics and for psychological distress or posttraumatic stress symptoms at the first survey. We used a two-step procedure. First, we examined the associations of radiation risk perceptions at the first survey with psychological distress and posttraumatic stress symptoms at the second survey, controlling for the socio-demographic, disaster-related, and social network characteristics. After that, we added psychological distress or posttraumatic stress symptoms at the first survey to the model to examine whether the associations of radiation risk perceptions remained significant.

All statistical analyses were performed using Stata 15 for Windows (StataCorp LP, College Station, TX). Statistical significance was set at .05 and all tests were two-tailed.

2.4. Ethical considerations

All procedures followed were in accordance with the Helsinki Declaration and its later amendments. The study protocol was reviewed and approved by the Research Ethics Committee of the University of Tokyo Graduate School of Medicine and Faculty of Medicine.

3. Results

From the 2,038 individuals who responded to the first survey, follow-up responses were obtained from 1,450 individuals. The analyses focused on the 1,148 participants with no missing information among the study variables (56.3% of the respondents in the first survey). We examined the differences between the study subjects and the respondents to the first survey not included in this study (Supplemental Table 1). Compared to the individuals removed, the analysis sample included more middle-aged people, more women, and more married individuals. They tended to have higher educational and income levels, and they were more likely to live in their own houses and belong to some social groups. However, the analysis sample was similar to the individuals removed with respect to radiation risk perceptions, psychological distress, and posttraumatic stress symptoms in the first survey.

Table 1 reports the socio-demographic characteristics, disaster-related experiences, social network characteristics, radiation risk perceptions, and psychological distress of the study subjects at the first survey and those of respondents with psychological distress at the second survey. The group with psychological distress at the second survey

Table 1
Socio-demographic, disaster-related, and social network characteristics, and radiation risk perceptions, psychological distress, and posttraumatic stress symptoms in the first survey of the study subjects and their relationships with psychological distress and posttraumatic stress symptoms in the second survey (n = 1,148).

	Total		K6 score [T2]			PCL-S6 score [T2]		
	n/mean	%/SD	High (5 or above)			High (17 or above)		
			n/mean	%/SD	p	n/mean	%/SD	p
Residential area								
Eastern coastal area (Hama-dori)	88	7.7	33	10.8	***	6	10.9	**
Central area (Naka-dori)	631	55.0	189	61.8		41	74.6	
Western area (Aizu)	429	37.4	84	27.5		8	14.6	
Age, years								
20-39	465	40.5	157	51.3	***	26	47.3	
40-64	411	35.8	102	33.3		20	36.4	
65+	272	23.7	47	15.4		9	16.4	
Mean (Standard Deviation)	*48.2*	*16.9*	*44.2*	*15.8*	***	*44.8*	*15.8*	
Sex								
Men	510	44.4	130	42.5		25	45.5	
Women	638	55.6	176	57.5		30	54.6	
Educational attainment								
Junior high school	130	11.3	31	10.1		8	14.6	
High school	582	50.7	160	52.3		29	52.7	
Junior or technical college	250	21.8	60	19.6		12	21.8	
University or graduate school	186	16.2	55	18.0		6	10.9	
Level of household income adjusted by household size								
Low	443	38.6	116	37.9		25	45.5	
Medium	554	48.3	154	50.3		27	49.1	
High	151	13.2	36	11.8		3	5.5	
Marital status								
Married	754	65.7	183	59.8	*	34	61.8	
Separated, divorced, bereaved, unmarried or unknown	394	34.3	123	40.2		21	38.2	
No. of family members in a household								
1 (oneself)	120	10.5	31	10.1		6	10.9	
2	261	22.7	75	24.5		12	21.8	
3+	767	66.8	200	65.4		37	67.3	
Mean (Standard Deviation)	*3.4*	*1.6*	*3.3*	*1.5*		*3.5*	*1.7*	
Living arrangement								
One's own house	978	85.2	245	80.1	**	44	80.0	
Other [a)]	170	14.8	61	19.9		11	20.0	
Physical disease under treatment (ref. none)	288	25.1	71	23.2		14	25.5	
Effects from the Great East Japan Earthquake								
Direct damage [b)]								
0	774	67.4	196	64.1	*	30	54.6	*
1	293	25.5	77	25.2		16	29.1	
2+	81	7.1	33	10.8		9	16.4	
Disaster-related family problems [c)]								
0	1058	92.2	264	86.3	***	41	74.6	***
1+	90	7.8	42	13.7		14	25.5	
Social network								
Family and friends (LSNS-6 [d)]) (score range: 0–30)	*14.7*	*6.0*	*12.2*	*5.9*	***	*12.7*	*6.3*	*
Belonging to some groups (ref. no)	854	74.4	199	65.0	***	36	65.5	
Radiation risk perceptions (score range: 7–28) [T1]	*15.0*	*4.3*	*16.1*	*4.5*	***	*19.5*	*4.2*	***
Psychological distress (score range: 0–24) [T1]	*3.4*	*4.5*	*7.4*	*5.3*	***			
Posttraumatic stress symptoms (score range: 6–30) [T1]	*8.4*	*3.6*				*14.1*	*6.5*	***

SD, standard deviation; T1: at the first survey, i.e., 5 years after the accident; T2: at the second survey, i.e., about 7 years after the accident or 21 months after the first survey.

*p < 0.05; **p < 0.01; ***p < 0.001.

[a] Rented house, temporary house, disaster restoration house, or acquaintance's or relative's house.

[b] No. of direct damage incidents experienced in any of the following: 1. Harm to oneself, 2. Harm or death of family members, 3. Loss of job or temporary absence from work, or 4. Loss of house or property.

[c] No. of family problems experienced in any of the following: 1. Deterioration of family relationships, or 2. Family separation.

[d] Lubben Social Network Scale - 6.

tended to consist of residents in coastal and central areas and younger populations. They were less likely to be married, tended to reside in dwellings that they did not own, had a smaller social network of family or friends, and were less likely to belong to groups. Furthermore, they were more likely to have disaster-related family problems. They perceived higher risk of radiation exposure and had greater psychological distress at the first survey.

Table 1 also reports these variables of the respondents with posttraumatic stress symptoms at the second survey. The group with posttraumatic stress symptoms at the second survey tended to consist of residents of coastal and central areas. Participants in this group had a smaller social network of family or friends. Furthermore, they were more likely to have experienced direct damage and disaster-related family problems. They perceived higher risk of radiation exposure and had more severe posttraumatic stress symptoms at the first survey.

The results of the multivariate logistic regression analyses of psychological distress are shown in Table 2. In Model 1, radiation risk perceptions at the first survey was significantly associated with psychological distress at the second survey after controlling for the socio-demographic, disaster-related, and social network characteristics. In Model 2, which added psychological distress at the first survey, the association of radiation risk perceptions with psychological distress at the second survey was no longer significant. We repeated the analyses using a cut-off point of 13 instead of 5 in the K6 to identify subjects with psychological distress in the second survey and found similar results. Specifically, radiation risk perceptions at the first survey was significantly associated with psychological distress at the second survey in Model 1 and its significant association did not remain in Model 2 (results not shown).

The results of a comparable analysis of posttraumatic stress symptoms are shown in Table 3. Radiation risk perceptions at the first survey was associated with posttraumatic stress symptoms at the second survey, controlling for the socio-demographic, disaster-related, and social network characteristics in Model 1. Moreover, the significant association of radiation risk perceptions was maintained in Model 2, which adjusted for posttraumatic stress symptoms at the first survey.

We repeated the analyses using the 5-item version of the radiation risk perception scale described in Methods and found similar results. That is, radiation risk perceptions at the first survey were significantly associated with both psychological distress and posttraumatic stress symptoms at the second survey before controlling for the baseline level of distress or symptoms. However, after controlling for the baseline level of distress or symptoms, the association of radiation risk perceptions with psychological distress was no longer significant, while the

Table 2
The association between radiation risk perceptions at the first survey and psychological distress at the second survey with adjusting for psychological distress at the first survey (n = 1,148).

	Model 1			Model 2		
	OR	95%CI		OR	95%CI	
Residential area (ref. Western area)						
Eastern coastal area (Hama-dori)	1.51	0.86	2.67	1.70	0.89	3.26
Central area (Naka-dori)	1.41	1.01	1.96	1.51	1.03	2.21
Age (ref. 65+)						
20–39 years old	2.21	1.33	3.67	2.08	1.18	3.69
40–64 years old	1.46	0.93	2.28	1.33	0.80	2.20
Sex (women)	1.17	0.87	1.57	0.88	0.63	1.24
Educational attainment (ref. University or graduate school)						
Junior high school	1.02	0.56	1.86	0.91	0.45	1.82
High school	0.98	0.65	1.47	0.94	0.59	1.50
Junior or technical college	0.73	0.45	1.17	0.78	0.45	1.34
Level of household income adjusted by household size (ref. High)						
Low	0.94	0.58	1.51	1.13	0.66	1.96
Middle	1.25	0.79	1.97	1.37	0.82	2.30
Marital status (Married)	0.92	0.66	1.28	1.09	0.74	1.60
Living alone	0.86	0.51	1.43	0.77	0.43	1.41
Living arrangement (One's own house)	0.76	0.51	1.13	0.90	0.57	1.43
Physical disease under treatment	1.39	0.95	2.06	1.33	0.85	2.08
Disaster-related experiences (ref. none)						
Direct damage [a)]						
1	0.83	0.58	1.17	0.66	0.44	0.99
2+	1.47	0.86	2.52	0.78	0.42	1.47
Disaster-related family problems [b)]						
1+	1.87	1.15	3.05	1.68	0.94	3.01
Social network						
Family and friends (LSNS-6 [c)])	0.91	0.89	0.94	0.95	0.93	0.98
Belonging to some groups	0.79	0.56	1.10	0.94	0.63	1.38
Radiation risk perceptions [T1]	1.07	1.04	1.11	1.01	0.97	1.06
Psychological distress [T1]				1.34	1.28	1.41

OR: odds ratio; CI: confidence interval; ref.: reference; T1: at the first survey, i.e., 5 years after the accident; T2: at the second survey, i.e., about 7 years after the accident or 21 months after the first survey.

[a] No. of direct damage incidents experienced in any of the following: 1. Harm to oneself, 2. Harm or death of family members, 3. Loss of job or temporary absence from work, or 4. Loss of house or property.

[b] No. of family problems experienced in any of the following: 1. Deterioration of family relationships, or 2. Family separation.

[c] Lubben Social Network Scale - 6.

Table 3
The association between radiation risk perceptions at the first survey and posttraumatic stress symptoms at the second survey with adjusting for posttraumatic stress symptoms at the first survey (n = 1,148).

	Model 1			Model 2		
	OR	95%CI		OR	95%CI	
Residential area (ref. Western area)						
Eastern coastal area (Hama-dori)	2.02	0.59	6.97	2.06	0.55	7.77
Central area (Naka-dori)	2.53	1.10	5.81	2.40	1.00	5.76
Age (ref. 65+)						
20–39 years old	1.23	0.42	3.59	1.44	0.47	4.47
40–64 years old	1.29	0.50	3.35	1.46	0.53	4.00
Sex (women)	0.90	0.49	1.64	0.74	0.39	1.42
Educational attainment (ref. University or graduate school)						
Junior high school	1.74	0.50	6.07	1.59	0.43	5.83
High school	1.26	0.48	3.29	0.97	0.36	2.63
Junior or technical college	1.11	0.37	3.31	1.07	0.36	3.20
Level of household income adjusted by household size (ref. High)						
Low	2.66	0.72	9.80	2.55	0.66	9.84
Middle	2.72	0.75	9.79	2.52	0.68	9.34
Marital status (Married)	0.82	0.40	1.66	1.00	0.47	2.13
Living alone	1.08	0.37	3.19	0.83	0.26	2.68
Living arrangement (One's own house)	0.79	0.35	1.78	0.75	0.32	1.72
Physical disease under treatment	1.32	0.61	2.87	1.32	0.58	3.02
Disaster-related experiences (ref. none)						
Direct damage [a)]						
1	0.69	0.34	1.40	0.51	0.23	1.11
2+	1.39	0.57	3.34	0.59	0.21	1.63
Disaster-related family problems [b)]						
1+	2.49	1.18	5.27	1.60	0.70	3.64
Social network						
Family and friends (LSNS-6 [c)])	0.96	0.91	1.01	0.97	0.92	1.02
Belonging to some groups	0.69	0.35	1.37	0.82	0.39	1.74
Radiation risk perceptions [T1]	1.25	1.16	1.34	1.19	1.10	1.29
Posttraumatic stress symptoms [T1]				1.23	1.15	1.31

OR: odds ratio; CI: confidence interval; ref.: reference; T1: at the first survey, i.e., 5 years after the accident; T2: at the second survey, i.e., about 7 years after the accident or 21 months after the first survey.

[a] No. of direct damage incidents experienced in any of the following: 1. Harm to oneself, 2. Harm or death of family members, 3. Loss of job or temporary absence from work, or 4. Loss of house or property.

[b] No. of family problems experienced in any of the following: 1. Deterioration of family relationships, or 2. Family separation.

[c] Lubben Social Network Scale - 6.

association with posttraumatic stress symptoms remained significant (results not shown). In addition, we repeated our analyses while excluding the 24 respondents who had moved since the nuclear power plant accident. Because we did not have their residence information at the time of the accident, we excluded all respondents who moved to eliminate the possibility that responses of the evacuees from the evacuation zone or of those who came from outside Fukushima prefecture biased our results. We obtained similar results (results not shown).

4. Discussion

Radiation risk perceptions five years after the nuclear power plant accident were significantly associated with psychological distress and posttraumatic stress symptoms two years later, before controlling for the baseline score of each measure. This finding is consistent with our first hypothesis. However, while radiation risk perceptions remained significantly associated with later posttraumatic stress symptoms after adjusting for initial symptoms, this was not the case for general psychological distress. Therefore, our second hypothesis was only partially supported.

Our study revealed that higher risk perceptions of radiation exposure were prospectively associated with later posttraumatic stress symptoms, which was in line with a previous study conducted among evacuees after the Fukushima nuclear power plant accident (Oe et al., 2017). Our study revealed that higher risk perceptions of radiation exposure also had a predictive relationship with posttraumatic stress symptoms among non-evacuee community residents living outside the evacuation zone. Thus, long-term follow-up of residents with high risk perceptions is needed irrespective of their actual level of radiation exposure.

In our study, higher risk perceptions of radiation exposure did not predict later psychological distress after controlling for baseline distress. This was in line with a two-wave study of evacuees after the Fukushima accident (Miura et al., 2017) and a longitudinal study conducted nine to 42 months after the TMI accident (Dew et al., 1987). However, it was inconsistent with other studies after the TMI accident which reported significant associations of perceived harm to health or dangerousness with later psychological distress (Dew & Bromet, 1993; Goldsteen et al., 1989). In these studies, the baseline level of psychological distress was not controlled. We also found a significant association of radiation risk perceptions with later psychological distress before controlling for the baseline distress values. Therefore, significant associations in these previous studies might be due to the baseline level of psychological distress which was not accounted for in the studies. There is ample evidence of cross-sectional correlations of radiation risk perceptions with psychological distress after nuclear power plant accidents (Adams et al., 2011; Fukasawa et al., 2017; Goldsteen et al., 1989; Niitsu et al., 2014; Oe et al., 2016; Suzuki et al., 2015). The major part of these correlations may be not causal, could be due to reporting bias, or may even stem from a tendency of individuals with psychological distress to perceive radiation's effects more negatively, rather than high risk perception itself causing psychological distress. Longitudinal studies after nuclear power plant accidents are still limited and more studies examining the temporal relationships of radiation risk perceptions and mental health controlling for relevant confounders are required.

Our study revealed that higher risk perceptions of radiation exposure contributed to later posttraumatic stress symptoms but not independently to later psychological distress, which might be explained by a disorder-specific cognitive vulnerability. Cognitive vulnerabilities have been explored in vulnerability-stress models, which have been applied to mental disorders to identify factors that are causally related to symptom development (Elwood et al., 2009; Riskind & Alloy, 2006). Individuals possessing certain kinds of cognitive styles are known to be vulnerable when exposed to negative life events. In vulnerability-stress models, exposure to a traumatic event activates inherent vulnerability and causes mental disorder. Furthermore, once the disorder has developed, it may also serve as a maintenance factor for psychological symptoms. "Looming cognitive style" is conceptualized as an anxiety-specific cognitive vulnerability (Riskind, 1997; Riskind et al., 2000). The looming cognitive style biases the processing of threat-related information and leads individuals tend to perceive potential threats as rapidly intensifying in risk or danger, which functions as an antecedent vulnerability to anxiety. The looming cognitive style was reported to explain a latent anxiety factor shared among several anxiety disorder symptoms including posttraumatic stress symptoms (Williams, Shahar, Riskind, & Joiner, 2005). It has been proposed as one of cognitive vulnerabilities in posttraumatic stress disorder (Elwood et al., 2009). Individuals with high risk perceptions of radiation exposure after nuclear power plant accidents may process radiation-related information with a looming cognitive style, that is, they tend to appraise potential threats caused by radiation exposure, such as adverse health effects, as rapidly approaching. Our result that high risk perceptions of radiation exposure only contributed to posttraumatic stress symptoms may partly be explained by this anxiety-specific cognitive vulnerability.

In a public health perspective, after a nuclear power plant accident, the study findings imply that continuous monitoring of risk perceptions of radiation exposure in neighboring communities is needed, possibly combined with providing accurate knowledge on radiation exposure and its health effects. Our findings on the association between radiation risk perceptions and posttraumatic stress symptoms seem to indicate that radiation risk perceptions partly stem from a cognitive style or reaction related to a traumatic experience in the disaster. Understanding, recognizing, and responding to high risk perceptions of radiation exposure as a traumatic experience may be a useful approach to reduce the impact of radiation risk perceptions on posttraumatic stress symptoms. It may be more appropriate and acceptable to emphasize physical and emotional safety than to challenge a radiation-related belief of individuals and populations, to empower and help survivors recover a sense of control in a post-disaster life.

5. Limitations

Our study has several limitations. First, the response rate of the baseline survey was not very high (41.6%), which might have caused a selection bias. For instance, if subjects with lower risk perceptions of radiation exposure or fewer psychological distress or posttraumatic stress symptoms were less likely to participate in the survey because of their lack of interest in these problems, the associations observed between radiation risk perceptions and psychological distress or posttraumatic stress symptoms might have been underestimated. Furthermore, our study subjects were not fully representative of the respondents in the baseline survey, although the level of radiation risk perceptions, psychological distress, and posttraumatic stress symptoms in the baseline survey were not significantly different. Our results were based on respondents who included more middle-aged people, women, those with higher socio-economic status, married, living in their own houses, and belonging to some groups, compared to the total respondents in the baseline survey. Thus the generalizability of our findings is limited. Second, the scale used to measure radiation risk perceptions in the present study has not been fully validated, and a possible two-factor structure has been suggested (Kawakami, 2013; Umeda et al., 2014). In the present study, we used the scale to represent the single construct of radiation risk perceptions based on the high internal consistency reported in a previous study (Cronbach's alpha coefficient 0.81; Kawakami, 2013; Umeda et al., 2014). Its internal consistency was also high in our study subjects (Cronbach's alpha coefficient 0.84). However, it is possible that these two factors are related to psychological distress and posttraumatic stress symptoms differently, which might have affected the present findings. Further research is needed to examine the relationships of different aspects of radiation risk perceptions with later mental health.

6. Conclusions

We conducted questionnaire surveys of a random sample of non-evacuee community residents of Fukushima prefecture at five and seven years after the nuclear power plant accident. Radiation risk perceptions at the first survey contributed to later posttraumatic stress symptoms independently from baseline symptoms. However, radiation risk perceptions did not contribute independently to later psychological distress. High risk perceptions of radiation exposure continuing for more than five years can lead to posttraumatic stress symptoms.

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Declaration of competing interest

None.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ssmph.2019.100523.

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