Journal of Risk Research, 2023, DOI: 10.1080/13669877.2023.2181856

Attitudes toward possible food radiation contamination following the Fukushima nuclear accident: A nine-year, ten-wave panel survey

Takashi Kusumi[a]*, Asako Miura[b], Kanayo Ogura[c] and Kazuji Nishikawa[a]

[a] *Graduate School of Education, Kyoto University; Graduate School of Human Sciences, Osaka University;* [c] *Faculty of software and Information Science, Iwate Prefectural University*

*Corresponding author. E-mail:kusumi.takashi.7u@kyoto-u.jp

Attitudes toward possible food radiation contamination following the Fukushima nuclear accident: A nine-year, ten-wave panel survey

After the Fukushima nuclear accident, we examined changes in risk perception regarding the radiation contamination of food and information-seeking behavior among residents of three regions progressively more distant from the disaster area, the Tokyo Metropolitan area to the Kansai area. We conducted a ten-wave panel survey and obtained data from 1,752 citizens six months to nine years after the accident. The results indicate that anxiety related to radioactive contamination, active information-seeking behavior, and avoidance of foods from affected areas decreased with time. Active information-seeking behavior and radiation-related knowledge were higher in the disaster-affected prefectures than in other areas. Conversely, avoidance of foods from affected areas was lower in affected prefectures than in the Kansai area. The credibility of government information increased from a considerably low level but did not reach the midpoint level. Multiple regression analysis, cross-lagged analysis, and structural equation modeling indicated that avoidance of foods from affected areas was promoted by anxiety related to radioactive contamination (experiential thinking/System 1) and inhibited by critical thinking attitudes (analytical thinking/System 2). Finally, we discussed the significance of risk literacy, which integrates risk-related knowledge, scientific literacy, media literacy, and critical thinking.

Keywords: risk perception; radiation hazard; dual-process model; critical thinking; 2011 Great East Japan Earthquake

1. Introduction

We investigated nine-year changes in attitudes toward possible radioactive contamination of food caused by the Fukushima Dai-ichi nuclear power plant accident after the Great East Japan Earthquake on March 11, 2011. We also compared regional differences in food attitudes depending on the distance from the nuclear power plant through a ten-wave panel survey conducted on the Internet. A nuclear reactor accident is a risk perceived as dreadful and unobservable (Slovic,1987). Nuclear accident consequences are not limited to the consequences of actual radiation. An area's population, products, or activities can be stigmatized even with low or decreased levels of accidental radiation (e.g., Gregory, Flynn, and Slovic.,1995; Poumadère and Mays,2014). The Fukushima Dai-ichi, nuclear power plant accident was a large-scale radiation accident comparable to the 1986 Chernobyl disaster (e.g., Belyakov, 2015; World Health Organization, 1990, 2013). The accident caused significant anxiety to citizens because the soil, sea, and food became contaminated, which was expected to cause health problems. The Japanese government attempted to reassure citizens by conducting press conferences and examining radioactive materials. Consequently, only food without contamination risks was marketed. However, specific customers, such as parents with small children, tended to avoid food produced in the affected areas because they were worried about health problems in their children caused by radioactive substances in food (Kanda et al. 2013; Sugimoto et al. 2014). Citizens who wished to reduce their anxiety or whose anxiety led them to proactively look for information sought reliable information about the effects of radiation on health through mass media and the Internet (Yumiya et al. 2019). However, there were diverse opinions concerning the impact of food radioactive contamination on health among administrators, the mass media, citizens' websites, and word of mouth, among others. Therefore, citizens were required to integrate these opinions. As a result, citizens needed to acquire scientific literacy (how to judge scientific information), media literacy (how to evaluate media information), and risk literacy (how to understand and use risk information), as well as critical thinking attitudes to support the above types of literacies (Kusumi, Kashima, and Hirayama, 2017). We will define these literacies further in Section 1.2.

1.1. Explanations of food avoidance using the Dual-process model

The present study's focus was attitudes about avoiding foods produced in radiation-affected areas. An unwarranted avoidance behavior can be regarded as a stigma and an excessively severe response to the perceived risk (Walker, 2013). Stigma is the outcome of widespread fears and perceptions of risk and a lack of trust in the management of technological hazards (Gregory, Flynn, and Slovic,1995).

The stigmatization of products can be analyzed in terms of a dual-process model (Schulze and Wansink, 2012). The dual-process model (e.g., Chaiken and Trope, 1999; Epstein, 1994; Sloman, 1996) assumes two processes: experiential thinking (System 1) is characterized by intuitive and quick judgments based on anxiety or fear about radiation, and analytical thinking (System 2) involves logical and analytical judgments based on critical thinking attitudes and risk literacy, among others. Kudo and Nakayachi (2014) applied the dual-process theory to examine attitudes toward food avoidance in Japan's radiation-affected areas. Information that a specific food was produced in a radiation-affected area functioned as a stigma for decisions to buy a particular food, which led to an attitude of food avoidance. With experiential thinking, this food avoidance attitude appears to be an excessive risk rejection response caused by an emotional decision-making process. Kudo and Nakayachi indicated that anxiety about radiation's effects on health suppressed buying behaviors with experiential thinking. In contrast, based on rational and deliberate reasoning, analytical judgments monitor experiential thinking judgments and promote the intention to buy. Although they did not directly address stigmatization, Ryu and Kim (2015) examined a sample of Korean people to test the heuristic/systematic information-processing model of risk perception after the Fukushima nuclear accidents. They found that self-rated ability, the accuracy of messages, and income had a positive impact on systematic processing but a negative effect on heuristic processing.

1.2. Conceptual framework of the study

As this study's conceptual framework, we posited the dual-process model indicated in Figure 1, consisting of intuitive and reflective cognitive processes. In the intuitive mental process of experiential thinking, anxiety about the health effects of radioactive contamination promotes the evaluation of information credibility and active information-seeking behaviors, leading to avoidance of food produced in the affected areas.

We focused on anxiety in experiential thinking because it was induced by contamination from unobservable radioactive materials and by the long-term and stochastic effects of radiation on health. We predicted that this thinking would cause stigmatization of situations and products related to radiation risk, leading to food avoidance. We predicted that anxiety about the health effects would be affected by the demographic variables of gender and having or not having children. Those who have children (e.g., Kanda et al.,2013) or women (e.g., Sugimoto et al., 2014) would feel more anxious.

H1a: Being a woman and having children enhance anxiety related to radioactive contamination.

H1b: Anxiety related to radioactive contamination causes food avoidance from affected areas.

On the other hand, in the reflective risk perception process of analytical thinking, critical thinking is the deliberative and reflective processing of information to reach a logical and rational conclusion based on evidence in order to make well-informed decisions about beliefs and actions (e.g. , Ennis, 1996). Critical thinking attitudes were expected to increase risk literacy about radiation, including knowledge of radiation, scientific literacy, and media literacy, which was expected to inhibit food avoidance (Miura, Kusumi, and Ogura， 2016). A critical thinking attitude that leads to critical thinking supports risk literacy (Kusumi, Hirayama, and Kashima, 2017). We focused on critical thinking attitudes because critical thinking is logical, objective, and evidence-based and a reflective means of consciously examining information in the intuitive risk perception process of experiential thinking.

Risk literacy is defined as the ability to deal with uncertainties in an informed way (Gigerenzer, 2012). In this study, risk literacy is the ability to obtain information related to risks, understand policies related to risks and strategies to decrease risks, and execute actions to reduce risks in various domains (e.g., health and natural disasters). The specific risk literacy examined in the present study, radiation risk literacy, encompasses knowledge about radiation, including radioactive substances and radiation units (i.e., radiation physics), and the understanding of radiation health effects supported by scientific literacy.

Scientific literacy is defined as a "level of understanding of scientific terms and constructs sufficient to read a daily newspaper or magazine and to understand the essence of competing arguments on a given dispute or controversy" (Miller, 1998). In this study, general scientific literacy is defined as an understanding of the process or nature of scientific inquiry (e.g., Miller, 1998). However, for appropriate decision-making, this understanding needs to be supplemented by specific scientific literacy, that is, knowledge about a specific domain relevant to a risk issue, which in the present case involves knowledge about nuclear radiation.

Media literacy is the ability to access, analyze, and evaluate mass media and apply critical thinking skills to understand messages from mass media and the Internet (e.g., Buckingham,2003). Media-literate individuals can access, analyze, and evaluate risk information provided by different media and take appropriate actions (Kudo and Nakayachi, 2014; Kusumi, Hirayama, and Kashima, 2017).

We, therefore, formulated the following hypotheses.

H2a: Critical thinking attitudes enhance risk literacy about radiation, including scientific literacy, media literacy, and knowledge.

H2b: Critical thinking attitudes and risk literacy about radiation inhibit avoiding food from affected areas.

1.3. Effects of elapsed time from nuclear accident and distance from the nuclear plant

Three years after the Fukushima nuclear accident, Poumadère and Mays (2014) pointed out that the social impacts of the nuclear accident included various removals of distance (geographic/national, political, social, temporal, and personal or private). The present study used several measures based on data obtained by directly asking citizens to examine whether the geographic distance and temporal distance were removed, that is, whether dependent variables such as anxiety related to radioactive contamination changed over time and whether there were regional differences.

Our results from the first to the fourth waves (reported in Miura, Kusumi, and Ogura, 2016) indicated that temporal distance removal did not occur uniformly, as anxiety, active information-seeking behavior, and the tendency to avoid local food did not decrease three years after the accident; however, critical thinking and risk literacy decreased during those three years. On the other hand, the effects of geographical distance removal were mixed, as anxiety, active information-seeking behavior, and radiation risk literacy (scientific literacy and media literacy) decreased with distance from the nuclear power plant; however, the tendency to avoid local food was more robust in the Kansai area, which is far from the disaster area. Takebayashi et al. (2020) found that local food avoidance among residents in the affected area prominently decreased five years after the accident, indicating that temporal removal did not occur.

The present study analyzes data up to the tenth wave, including data from the first four waves, to examine changes in risk perception indices, including anxiety, local food avoidance indices, literacy-related indices, and regional differences. We hypothesized that a further trend of decline with time and distance would emerge over nine years and that removal because of geographic distance and temporal distance would not necessarily occur.

H3a: Anxiety related to radioactive contamination, local food avoidance, and risk literacy declines over time.

H3b: Anxiety related to radioactive contamination, local food avoidance, and risk literacy decreases with distance from the nuclear power plant.

As a result of their anxiety and critical thinking attitudes, citizens proactively collect information by assessing different information sources (e.g., Yumiya et al., 2019). The present study examined how the information sources changed and were evaluated, as well as the time course of changes and regional differences in the time spent watching TV news, using the Internet, and talking with partners. This study also examined the information credibility of the various sources. Information credibility is defined as the extent to which one perceives the information to be believable (e.g., Tateno and Yokoyama, 2013). Evaluation of the credibility of information from each source would be expected to increase over time as more information becomes available, compared to the period immediately after the accident when no reliable information was available (e.g., Tateno and Yokoyama, 2013). We developed the following hypotheses.

H4a: Time spent watching TV news, using the Internet, and talking with partners about radiation declines over time.

H4b: The credibility evaluation of information from each source increases over time.

2. Method

2.1. *Survey period*

The study's first wave was conducted in September 2011, and the second wave in March 2012. We conducted additional waves, from the third in 2013 to the tenth in 2020, in late February or March, through the Internet.

2.2. *Participants*

Participants were members of a survey pool registered with MACROMILL, an online research company. All participants were married[1] and aged 20-50 years, and 28.1% had no children. All participants lived in three regions of Japan: (a) the area directly affected by the Great East Japan Earthquake, including Fukushima, Miyagi, and Iwate prefectures, approximately 0-250 km from the Fukushima Daiichi nuclear power plant; (b) the Tokyo Metropolitan area, including Tokyo, Chiba Saitama, and Kanagawa prefectures, approximately 200-300 km from the power plant; or (c) the Kansai area, including Kyoto, Osaka, and Hyogo prefectures, approximately 550-650 km from the power plant. Participants (n =584 from each area) took part in the survey. The number of participants in the first wave was 1,752 (876 men and 876 women, age *M*=40.1 years, *SD*=10.4). These participants were requested to participate in all waves after the second wave and received reward points each time they participated. The effective sample size in each wave decreased with time (Table 3). The participants' demographic attributes surveyed at the first wave included six occupational categories: office workers in private

[1] We chose married people as respondents so that we could ask them about the time they spent talking with partners.

companies (40.5%), housewives or househusbands (28.3%), part-time workers (16%), self-employed workers (6.3%), civil servants (4.8%), or executive officers (2.3%). Participants' educational background was categorized into three groups: university graduates (39.6%), high school graduates (27.1%), and junior college or specialized training college graduates (23.8%). Participants' annual household income was categorized into five groups: less than 3.49 million yen (USD 30,100; 14.2%), 3.5-9.9 million yen (USD 30,200-85,000; 64.9%), more than 10 million yen (USD 86,300; 10.1%), no answer (7.2%), and don't know (3.8%). Dual-income families were 47.1% of the participants.

The percentages of participants who reported experiencing effects of the disaster to some extent, including damage to the house, loss of a job, or a change of residence, among others, were 35.4% in the affected area, 4.1% in the Tokyo Metropolitan area, and 1.5% in the Kansai area.

2.3. Materials and procedures

A questionnaire was developed to assess risk perception of the nuclear accident caused by the Great East Japan Earthquake and subsequent radiation hazards.

2.3.1. Anxiety, active information-seeking behavior, and food avoidance

"Anxiety related to radioactive contamination" (two items), "active information-seeking behavior" (three items), and "food avoidance" (two items) were assessed using the items in Table 1. The responses to these items were made on a five-point Likert scale ranging from 1 (*Disagree)* to 5 (*Agree*), as in Miura, Kusumi, and Ogura (2016). Cronbach's alphas of these scales were .71, 68, and .73 at Time 1 of this study.

2.3.2. Thinking attitude and literacy

Critical thinking attitudes were assessed by a short version (12 items) of the Critical Thinking Attitude Scale for Japanese, initially developed by Hirayama and Kusumi (2004; 33 items) and later modified by Kusumi, Kashima, and Hirayama (2017; 15 items). This scale assessed four components of critical thinking attitudes, each with three items: logical approach, inquisitiveness, objectivity, and reliance on evidence. Responses were made using a five-point Likert scale ranging from 1 (*Disagree*) to 5 (*Agree*). Cronbach's alpha of this scale was .92 at Time 1.

Media literacy was assessed using the Media Literacy Scale (five items) for Radiation Risks (Kusumi, Kashima, and Hirayama, 2017) with a five-point Likert scale ranging from 1 (*Disagree*) to 5 (*Agree*). Cronbach's alpha of this scale was .92 at Time 1.

Scientific literacy was assessed based on the General Scientific Literacy Scale (Kusumi, Kashima, and Hirayama, 2007). We added a specific scientific literacy item, “Negative effects of low-dose radiation increase the risk of health problems.” The participants were asked to choose either “know” or “don’t know.” Items were scored by calculating the ratio of “know” responses (nine items, Cronbach’s α =.84).

2.3.3. Knowledge of radiation

The knowledge test on “knowledge about the health effects of radiation” and “knowledge of radiation physics” was conducted using the three questions in Table 1. Participants were asked to choose one of five options (four specific alternatives or “don’t know”) for all questions (Miura, Kusumi, and Ogura, 2016). The correct answers and explanations were provided to participants after the tests. The knowledge test was conducted at the first wave and every wave after the fourth wave.

“Subjective knowledge of radiation” was assessed by evaluating the knowledge of radiation and radioactive substances (nine items, Cronbach’s α =.93), as shown in Table 1. The participants responded to each item using a five-point Likert scale ranging from 1 (*Know very little*) to 5 (*Know well*).

2.3.4. Information credibility

Participants were requested to evaluate the credibility of 16 information sources they used when seeking information on radiation’s health effects, as shown in Table 1. There were three subscales, government, mass media, and word of mouth/citizen websites, comprising four, two, and two items, respectively, Cronbach's αs =.96, .81, .78). The participants evaluated each item using a five-point Likert scale ranging from 1 (*Incredible*) to 5 (*Credible*).

2.3.5. Information about the nuclear disaster and radiation and conversations

The average time spent on weekdays watching TV news programs and surfing the Internet to acquire information about the nuclear disaster and radiation doses was measured on a seven-point scale (Never, less than 15 minutes, 15-30 minutes, 30-60 minutes, 1-2 hours, 2-4 hours, and over 5 hours). The average time spent talking with their partner per day about such topics was also measured on a seven-point scale (*Never, less than 5 minutes, 5-15 minutes, 15-30 minutes, 30-60 minutes, 1-2 hours,* and *over 2 hours*).

3. Results

Data analysis based on our hypotheses (H1a-H4b) was conducted in four steps.

First, the preliminary analysis indicated that the 10-wave residual panels did not differ from the dropout panel on any demographic variable or critical indicator. Using the new panel as a control group revealed only minor differences between the remaining panel and the new panel (for details, see the preliminary analysis in the Appendix A).

Second, the descriptive statistics of the primary analysis revealed differences in means and correlations of risk perception (H1b, H3a, H3b), critical thinking, literacies, and knowledge (H2a, H2b) and credibility (H4b) after six months, at one to nine years, and between the three regions progressively distant from the disaster area.

Third, we compared the results after six months and nine years by SEM based on the hypothetical model in Figure 1 to examine the effects of experiential and analytical thinking (System 1 and System 2) on food avoidance (H1a, H2a, H2b). A cross-lagged model (Kenny, 2005) was used to investigate the influence of experiential and analytical thinking variables on the following time points in each of the nine waves. In addition, regression analysis examined the effects of experiential and analytical thinking on food avoidance at each wave (H1b, H2b).

Finally, we examined the time course of changes and regional differences in credibility and the time spent on information sources (H4a, H4b).

3.1. Main analyses

3.1.1. Risk Perception and Related Indices (Time 1 & Time 10)

The means (SDs) and the results of paired t-tests, as well as Cohen's *d*s of the leading indices at Time 1 (six months after the accident) and Time 10 (nine years after the accident), are shown in the lower part of Table 2. Anxiety and active information-seeking behavior declined considerably from six months to nine years after the accident

(H3a). “Subjective knowledge about radiation” declined significantly, and scientific literacy and knowledge of radiation physics also declined, whereas knowledge of radiation health effects increased. Ratings of government information credibility increased slightly（H4b）, while avoidance of food from the affected area, critical thinking attitudes, and media literacy decreased[2].

The third and subsequent columns of Table 2 provide correlation coefficients between indices at Time 1 and Time 10. Anxiety at Time 1 had high positive correlations with active information-seeking behavior and food avoidance from the affected area (H1b), which declined slightly at Time 10. Active information-seeking had moderate positive correlations with avoidance of food from the affected area, critical thinking attitudes, media literacy, and subjective knowledge of radiation at Time 1, all

---

[2] The second column of Table 2 shows scale reliabilities (Cronbach’s α) at Time 1, which for self-rating scales ranged between .68 and .93, indicating a sufficient level of reliability. The α coefficients for the scales of knowledge of radiation health effects and radiation physics knowledge were low. This finding may reflect differences in the scores analyzed, ranging from correct response rates to responses to four-item rating scales.

of which declined at Time 10 except for subjective knowledge of radiation. At Time 1, food avoidance had a weak negative correlation with knowledge of radiation health effects but a weak positive correlation with media literacy. At Time 10, food avoidance had weak negative correlations with knowledge of radiation health effects and media literacy, scientific literacy, critical thinking attitudes, and subjective knowledge of radiation (H2b). Critical thinking attitudes had moderate positive correlations with media and scientific literacy (H2a). Subjective knowledge of radiation was correlated slightly more strongly with radiation physics knowledge than with knowledge of radiation effects.

The credibility of government information had weak negative correlations with anxiety related to radiation, food avoidance, and active information-seeking at Time 1. The weak negative correlation with anxiety did not change at Time 10, whereas the correlations with active information-seeking behavior and food avoidance declined. The credibility of mass media information showed the same pattern as that of government at Time 1, whereas at Time 10, negative correlations, except for food avoidance, decreased. On the other hand, the credibility of information from citizen websites and word of mouth showed weak positive correlations with anxiety related to radiation, food avoidance, and active information-seeking at Times 1 and 10. Especially at Time 10, the weak positive correlation with active information-seeking behavior slightly increased. Mean credibility scores for 11 information sources are shown in Table B1 in the Appendix B.

3.1.2. Time-series changes and differences by residential area for risk perception

We examined time-series changes and differences by distance from the nuclear power plant for the nine significant variables. Figure 2 shows the mean values for all participants at each point in time. We conducted a two-way ANOVA (9 time points x 3 areas) on participants' responses in all ten waves.

The first row of Figure 2 shows the indices related to risk perception.

(a) The main effect of time on anxiety related to radiation contamination was significant ($F(8.19, 2089.02) = 29.30$, $p<.001$, partial $\eta^2 = .10$). However, neither the main effect of area ($F(2, 255) = 0.37$, $p = .69$, partial $\eta^2 = .003$) nor the interaction ($F(16.38, 2089.02)=1.19$, $p=.26$, partial $\eta^2 = .01$) was significant. These results suggest that anxiety declined with time over nine years in all three areas, approaching the midpoint of the scale (H3a).

(b) The main effect of time on active information-seeking was significant ($F(8.24, 2100.25)=16.09$, $p<.001$, partial $\eta^2 = .06$), but information-seeking declined with time, approaching the midpoint after the fifth year, and fell below the midpoint after the seventh year. The main effect of the area was significant ($F(2,255)=3.50$, $p=.03$, partial $\eta^2 = .03$); information-seeking was higher in the disaster-affected area than in the Kansai area (Bonferroni's multiple comparison test $p<.05$) (H3b). However, the interaction was insignificant ($F(16.47, 2100.25)=1.38$, $p=.14$, partial $\eta^2 = .01$).

(c) The main effect of time on avoidance of food from the affected area was significant ($F(7.42, 1890.88)=2.51$, $p = .012$, partial $\eta^2 = .01$). The main effect of area ($F(2, 255)=1.75$, $p=.18$, partial $\eta^2 = .01$) and the interaction ($F(14.83, 1890.88)=0.70$, $p=.81$, partial $\eta^2 = .005$) were not significant. Food avoidance in the Kansai area started at the midpoint, slightly increased three years later, and decreased after the fourth year. Food avoidance started below the midpoint in the other two areas and gradually declined and, after the sixth year, significantly declined in the affected area (H3a). Positive responses ("agree" and "somewhat agree") for the item "I don't want to eat food from the areas contaminated by radioactive materials even if the concentration of contamination is below the safety standard" decreased from 35% (six months later) to 19% (nine years later). Negative responses ("disagree" and "somewhat disagree") for this item increased from 33% to 39%, and neutral responses increased from 33% to 42% at these times. These results indicate that avoiding or accepting food from affected areas was similar after six months. Avoidance decreased, and neutral responses and acceptance increased slightly nine years after the accident.

As shown in Figures 2a, 2b, and 2c, the mean ratings of risk perception indices, including anxiety, active information-seeking behavior, and food avoidance from affected areas, decreased over the nine years of the study. These findings supported the hypothesis (H3a). The decrease in active information-seeking behavior rating was moderate from six months to nine years after the accident, and food avoidance ratings were also small. Of these risk perception indices, only information-seeking decreased with distance from the nuclear power plant, partially supporting hypothesis H3b.

3.1.3. Time-series changes and differences by residential areas in the literacy-related indices.

The second row of Figure 2 shows the literacy-related indices.

(a) The main effect of time on critical thinking attitudes was significant ($F(8.00, 2040.30)=4.47$, $p<.001$, partial $\eta^2=.02$), indicating a slight decline of literacy to above the midpoint after nine years (H3a). However, neither the main effect of area ($F(2, 255)=0.48$, $p=.62$, partial $\eta^2=.004$) nor the interaction ($F(16.00, 2040.30)=1.00$, $p=.46$, partial $\eta^2=.008$) was significant.

(b) The main effect of time on media literacy was significant ($F(8.24, 2101.46)=5.27$, $p<.001$, partial $\eta^2=.02$) but declined after the fifth year (H3a). The main effect of area (F(2, 255)=0.69, $p=.50$, partial $\eta^2=.005$) and the interaction (F(16.48, 2101.46)=1.11, p=.34, partial $\eta^2=.009$) were not significant.

(c) Scientific literacy was assessed based on the response rate of "know," and the main effect of time was significant (F(8.28, 2112.43)=5.86, p<.001, partial $\eta^2=.02$). However, neither the main effect of area (F(2,255)=2.94, $p=.06$, partial $\eta^2=.02$) nor the interaction (F(16.57, 2112.43)=0.39, p=.99, partial $\eta^2=.003$) was significant. These results indicate that scientific literacy gradually declined in all three areas (H3a).

The third row of Figure 2 shows the indices related to knowledge of radiation.

(a) The main effect of time on knowledge of radiation health effects was significant (F(6.20, 1581.08)=10.26, p<.001, partial $\eta^2=.04$). After the accident, the knowledge level was slightly higher than the chance level (25%), and the correct response rate increased after the fourth year. The main effect of the area was also significant (F(2, 255)=4.68, $p=.01$, partial $\eta^2=.04$). People in the affected area had better knowledge of radiation than those in the Kansai area (ps<.01). However, the interaction was insignificant (F(12.40,1581.08)=1.23, p=.25, partial $\eta^2=.01$).

(b) The main effect of time on knowledge of radiation physics was significant (F(6.67, 1700.42)=3.04, $p=.004$, partial $\eta^2=.01$). This knowledge was highest six months after the accident when the frequency of broadcasts was high, and then gradually declined (H3a). The main effect of the area was also significant ($F(2, 255)=5.43$, $p = .005$, partial $\eta^2 = .04$). People in the affected area and the Tokyo Metropolitan area had more knowledge than those in the Kansai area (ps<.01) (H3b). However, the interaction was insignificant ($F(13.34,1700.42)=1.56$, $p=.09$, partial $\eta^2 = .01$).

(c) The main effect of time on subjective knowledge of radiation was significant ($F(7.67, 1956.22)=21.264$, $p<.001$, partial $\eta^2 = .08$), and the main effect of the area was also significant ($F(2, 255)=14.08$, $p < .001$, partial $\eta^2 = .10$). However, the interaction was not significant ($F(15.34, 1956.22)=0.57$, $p=.93$, partial $\eta^2 = .004$). Subjective knowledge was highest in the affected area, followed by the Tokyo Metropolitan and Kansai areas (ps<.05). Subjective knowledge gradually declined in all three regions over nine years.

The ratings of literacy-related indices (Figures 2d, 2e, and 2f) also decreased over nine years, although the effect size was small; this generally supported hypothesis H3a, with one exception. Over nine years, the increase in knowledge about radiation's health effects (Figure 2g) was a minor effect because incorrect information, such as "having nose bleeds is caused by radioactive materials," was corrected within six months after the accident. The effect size of the decrease in knowledge about radiation physics was negligible (Figure 2h), and the effect size of the reduction of subjective knowledge about radiation was moderate (Figure 2i). Because knowledge about radiation's health effects is essential for survival, the acquired knowledge did not decay. Nevertheless, the knowledge of radiation physics and subjective knowledge decreased as the frequency of mass media reports decreased. Of the literacy-related indices, only subjective knowledge decreased with distance from the nuclear power plant, partially supporting hypothesis H3b.

3.1.3. Time-series changes and differences by residential areas in information credibility

The bottom row of Figure 2 shows the indices related to information credibility.

(a) Non-significant effects emerged for the main effect of time on the credibility of mass-media information ($F(7.54, 1921.63)=.81$, $p=.58$, partial $\eta^2=.003$), the main effect of area ($F(2, 255)=0.08$, $p=.92$, partial $\eta^2=.001$), and the interaction ($F(15.07, 1921.63)=1.01$, $p=.44$, partial $\eta^2=.008$).

(b) The main effect of time on the credibility of information from citizen websites and word of mouth was not significant ($F(8.07,2057.99$, $p=.11$, partial $\eta^2=.006$). The main effect of the area was significant ($F(2, 255)=3.31$, $p=.04$, partial $\eta^2=.025$), with lower information credibility in the affected area than in the Kansai area

(p<.05). The interaction was not significant (F(16.85, 2057.99)=0.70, p=.80, partial η^2 = .005).

(c) The main effect of time on the credibility of government information was significant (F(6.82, 1740.24)=17.34, p < .001, partial η^2 = .064) (H4a). However, neither the main effect of area (F(2, 255)=0.46, p = .63 partial η^2 = .004) nor the interaction (F(13.64, 1740.24)=1.38, p=.16, partial η^2 = .011) was significant.

The perceived credibility of government information was deficient initially and did not reach a moderate level after nine years. However, it increased to a level equal to the perceived credibility of citizen websites and word-of-mouth information, which was below the midpoint and did not change over time, despite a moderate effect size. On the other hand, the perceived credibility of mass media information was moderate and did not change (Figures 2j, 2k, and 2l, Table A1). Therefore, hypothesis H4b was partially supported.

3.1.4. Determinants of food avoidance: Multigroup SEM analysis after six months and nine years

Determinants of food avoidance from the disaster-affected area were compared between the three areas and between times six months and nine years later using multigroup structural equation modeling (covariance-based SEM, AMOS ver. 27)

(Figure 3). We proposed the following model and examined it based on the hypothetical model shown in Figure 1 and correlation coefficients indicated in Table 2: (a) anxiety in experiential thinking would affect active information-seeking behavior and the perceived credibility of administrative information; (b) critical thinking attitudes in analytical thinking would affect media literacy, active information-seeking behavior, and the perceived credibility of administrative information (H2a); (c) media literacy and active information-seeking behavior would inhibit food avoidance (H2b); (d) being a woman, having children, and living near the affected areas would increase anxiety (H1a).

Goodness-of-fit indices (CFI = .95, and RMSEA = .03×√2) shown in Figure 3 suggest an excellent fit to the model. Path coefficients indicated that (a) anxiety strongly promoted active information-seeking behavior and decreased the perceived credibility of administrative information six months and nine years later; (b) critical thinking attitudes increased media literacy; (c) active information-seeking behavior strongly promoted food avoidance, whereas media literacy suppressed food avoidance (H2b), and (d) being a woman and having children increased anxiety (H1a). The tendency of media literacy to decrease the perceived credibility of government information was observed only after six months.

3.1.5. Time-series changes in determinants of food avoidance at ten time points

Figure 4 shows the results of examining the effects of three essential determinants--anxiety (ANX), critical thinking attitudes (CT), and active information-seeking behavior (INF)--on avoidance of food from affected areas (AVO) at the next point in time using all the data and employing a cross-lagged model. Goodness-of-fit indices (CFI = .83 and RMSEA = .03) suggest a good fit of the model.

The results indicate that anxiety at six months and one, two, four, five, seven, and eight years after the nuclear accident promoted food avoidance at the next point in time (H1b). Critical thinking attitudes at six months and one, two, three, four, six, and eight years after the accident suppressed food avoidance at the next point in time (H2b). Furthermore, critical thinking attitudes promoted active information-seeking behavior at six months and two, three, four, six, and eight years after the accident. Active information-seeking behavior at two years and six years after the accident promoted anxiety at the next point in time. Food avoidance at six months and from one to eight years after the accident also promoted anxiety at the next point in time. Finally, low food avoidance promoted critical thinking attitudes at six months, two years, five years, and seven years.

Table 3 shows the results of multiple regression analysis with food avoidance as an objective variable and age, children's presence, distance from the nuclear power plant, anxiety, and critical thinking attitudes as explanatory variables. The contribution ratios of these variables were 23-33%. Standardized partial regression coefficients indicate that the promoting effect of anxiety related to radioactive contamination (H1b) gradually decreased over nine years. In contrast, the suppressive effect of critical thinking attitude (H2b) gradually increased. However, there was little interaction between these variables. The contribution of three demographic characteristics (being a woman, having children, and having a shorter distance from the nuclear power plant) to food avoidance was small (5%). However, the suppressive effect of age and the promoting effect of distance from the nuclear power plant slightly increased with time. Moreover, having children always promoted food avoidance (H1a). The standardized partial regression coefficients of the panel data collected in the eighth year of the remaining panel and the new samples showed almost the same pattern.

3.1.6. Contacts with information related to nuclear disasters, radiation doses, and conversation

Figure 5 shows changes in the time spent watching TV news, using the Internet, and having conversations with one's partner to get information about the nuclear disaster, radiation doses, and the health effects of radiation. The time spent getting information through TV news, the Internet, and conversations decreased over the nine years in all three areas (H4a). Conversely, the percentage of participants whom neither gathered information nor had conversations increased. More time was spent watching TV news than using the Internet partly because, except for the first wave, the survey was conducted every year in March, when programs related to the disaster were often broadcast. More time was spent watching TV news in the disaster-affected area than in the Tokyo Metropolitan and Kansai areas. The percentage of participants who watched TV for an extended time was also higher in the affected area. The time spent using the Internet was the longest in the affected area, followed by the Tokyo Metropolitan area and the Kansai area. Slightly more people used the Internet for more than 15 minutes a week in the affected area than in the other regions (H4b). Finally, the proportion of participants who answered that they and their partners do not have conversations at all about nuclear disasters and radiation doses increased from 13% to 56% in the affected area, from 17% to 67% in the Tokyo metropolitan area, and from 27% to 65% in the Kansai area from six months to nine years later.

The time spent watching TV news, using the Internet, and having conversations with one's partner decreased over the study's nine-year period (Figure 5). Therefore, hypotheses H4a and H4b were generally supported.

4. Discussion

4.1. Nine-year time-series changes in determinants of food avoidance

Avoidance of food from affected areas appears to have been affected by two systems. First, with experiential thinking, increased health anxiety promoted active information-seeking and food avoidance behavior based on emotional and intuitive decision-making. Such anxiety was high in child-rearing mothers (Figure 3). These findings supported hypotheses H1a and H1b. The promoting effect of anxiety on food avoidance decreased slightly over the nine years of this study. Second, the logical decision-making process of analytical thinking promoted critical thinking attitudes and improved media literacy, which suppressed food avoidance (Figure 4). These findings supported hypotheses H2a and H2b. This process was relatively weak compared to the effect of anxiety just after the accident but gradually became more robust with time (Table 3). The above results are consistent with a previous study (Takebayashi et al., 2020). The present study newly demonstrated the suppressive effects of critical thinking attitudes and media literacy with analytical thinking. These suppressive effects gradually increased with time, although they remained relatively weak compared to the impact of anxiety.

4.2. Research contexts and possible impacts on findings

The present study followed risk perception changes in Japanese citizens who had experienced the Fukushima Dai-ichi nuclear power plant accident, the most severe nuclear accident since the Chernobyl disaster. There are three characteristic contexts of this disaster.

First, Japanese citizens had significant anxiety because they did not know the long-term health effects of radioactive food contamination, as indicated by the high anxiety ratings six months after the disaster (Figure 2i). Mothers rearing children had especially intense anxiety, and some citizens began to avoid food produced in the disaster-affected area (H1a and H1b, Figure 3).

Second, Japanese citizens distrusted their government, which held frequent press conferences to reassure Japanese citizens by saying, "there are no immediate effects on health.". Although the low level of trust in government information after one year had been noted in Tateno and Yokoyama (2013), a long-term gradual recovery to the midpoint level was newly found here (H4b, Figure 2). Therefore, citizens actively sought to gather information from different sources, such as the mass media, citizen websites, and word of mouth, among others, especially during the first year after the accident. Of these information sources, scientists' warnings about the risk had the highest credibility (Appendix B, Table B1). Japanese citizens were thus confronted with much different information from different sources (e.g., Nakayama et al., 2019).

Third, it was essential for Japanese citizens to select appropriate behaviors by judging information using their media literacy and critical thinking attitudes, as reflected in their scores for media literacy, scientific literacy, knowledge of radiation physics, and subjective knowledge of radiation six months after the accident. However, the use of mass media and active information-seeking behavior gradually decreased with time (H4a; Figures 2b, 5b). On the other hand, knowledge of radiation health effects gradually increased with time as experiences accumulated, reducing the perception of risk related to the health effects of radiation and health anxiety (H3a; Figures 2a, 2g).

These three characteristics were evident in the aftermath of the Fukushima Dai-ichi nuclear power plant accident and are likely to appear in any future nuclear accidents or other large-scale hazards. These characteristics were also found during the COVID-19 pandemic (e.g., Paakkari and Okan, 2020; Roozenbeek et al., 2020): (a) an increase in anxiety caused stigmatization, discrimination, and avoidance of people who were regarded as dangerous, such as infected persons and health care workers, among others (Yoshioka and Maeda, 2020); (b) an increase in distrust of government information and risk perception (e.g., Dryhurst et al.,2020) and active information-seeking behavior; (c) vital roles for media literacy, scientific literacy, health literacy, knowledge, and critical thinking attitudes (e.g., Nakayama, et al., 2019).

Based on the present results, our recommendations to any government responding to a crisis are (a) to provide the public not only with reassuring information about health effects but also with accurate risk and coping information and (b) to manage risk communication from the early stages of a disaster to reduce anxiety, especially among high-risk individuals such as mothers raising children. At the same time, it is important to send out messages that promote analytical thinking to reduce anxiety.

4.3. Limitations and conclusions

Several limitations of the present study should be noted. First, the surveys after the second wave were conducted every year in March, the time of the nuclear accident's anniversary, when TV programs related to the accident are frequently broadcast. Thus, participants were likely made especially conscious of radiation risks. Participants were also affected when something related to the accident happened during the survey period. For example, in March 2017, the evacuation order in three towns and villages in the affected area was lifted, which increased the time spent watching TV news (Figure 5a), using the Internet (Figure 5b), and talking with one's partner (Figure 5c), compared to the previous point in time.

Second, nuclear accidents may cause a variety of distance removals that affect society (Poumadère, & Mays, 2014), but only two of them were examined here. For temporal distance, removal was not observed because the various measures, such as anxiety, decreased over the nine years. For geographical distance, the effect of removal was mixed, as anxiety and local food avoidance were affected in different directions for residents close to and far from the nuclear power plant. Examination of the removal of national/political/social/personal (private) distance would more precisely elucidate the impact of the Fukushima nuclear accident on long-lasting social disruption.

Third, the survey conducted in February and March of 2020 (the tenth wave) was affected by COVID-19. Significant changes in the values of the main indices, such as radiation health effects (Figure 1) or in the multiple regression analysis results (Table 3), were not observed until the ninth wave. Furthermore, the number of people infected by the coronavirus increased from late February to March. However, this did not produce a significant difference in the responses of February and March participants for the three indices of radiation risk perception (anxiety, active information-seeking behavior, and food avoidance) and three indices of literacy (critical thinking attitudes, scientific literacy, and media literacy). Although we did not ask participants about risk perception for COVID-19, previous studies have indicated that an increase in attention to new risks decreases the perception of previous risks (Nakayachi, Yokoyama, and Oki, 2015). Further analysis of these issues is advisable.

The present study examined the determinants of food avoidance produced in disaster-affected areas through a ten-wave panel survey conducted in three regions over nine years after the Fukushima Dai-ichi nuclear power plant accident. The strong effect of anxiety on food avoidance with experiential thinking gradually decreased with time, whereas the weak impact of critical thinking attitudes on food avoidance with analytical thinking steadily increased. When radiation health effects were unclear, citizens who could not trust government information soon after the accident played an active role by proactively collecting information from various sources. This helped them cope with their anxiety positively, increased their knowledge, and improved their media literacy, scientific literacy, and critical thinking attitudes. This is a crucial finding. We suggest that risk literacy, which integrates knowledge of risks, science and media literacy, and critical thinking, is essential for citizens to collect and judge information from different sources and take appropriate action to face a “risk society” (Beck, 1991).

Acknowledgement

The authors thank the Global Education Office, the Graduate School of Education, Kyoto University, for providing support for publishing the paper.

Disclosure statement

No potential conflict of interest was reported by the authors.

Additional information

Funding

This research was supported by a Grant-in-Aid for the Japan Society for the Promotion of Science (22228003, 15H02465, 19H00962).

Notes

1 We chose married people as respondents so that we could ask them about the time they spent talking with partners.

2 The second column of Table 2 shows scale reliabilities (Cronbach's α) at Time 1, which for self-rating scales ranged between .68 and .93, indicating a sufficient level of reliability. The α coefficients for the scales of knowledge of radiation health effects and radiation physics knowledge were low. This finding may reflect differences in the scores analyzed, ranging from correct response rates to responses to four-item rating scales.

References

Beck U. 1991. *Ecological enlightenment: Essays on the politics of the risk society*. Amherst, NY: Prometheus Books.

Belyakov, A. 2015. From Chernobyl to Fukushima: an interdisciplinary framework for managing and communicating food security risks after nuclear plant accidents. *Journal of Environmental Studies and Sciences* 5: 404–417. doi:10.1007/s13412-015-0284-2

Buckingham D. 2003. *Media education: Literacy, learning and contemporary culture.* Cambridge. MA: Polity Press.

Chaiken, S. and Trope, Y. 1999. *Dual-process theories in social psychology*. New York: Guilford Press.

Dryhurst, S., Schneider, C. R., Kerr, J., Freeman, A. L., Recchia, G., Van Der Bles, A. M., Spiegelhalter, D., and van der Linden, S. 2020. "Risk perceptions of COVID-19 around the world." *Journal of Risk Research* 21(7): 1-13. doi: 10.1080/13669877.2020.1758193

Ennis, R. H. 1996. *Critical thinking*. Upper Saddle River, NJ: Prentice-Hall.

Epstein, S. 1994. "Integration of the cognitive and the psychodynamic unconscious." *American Psychologist* 49: 709–724. doi: 10.1037/0003-066X.49.8.709

Gigerenzer, G. (2012). Risk literacy. In J. Erockman (Ed.) *This will make you smarter:*

New scientific concepts to improve your thinking (pp. 259-261). NY: Harper Perennial.

Gregory, R., J. Flynn, and Slovic., P. 1995. Technological stigma. *American Scientist* 83(3): 220-223.

Hirayama R., and Kusumi T. 2004. "Effect of critical thinking disposition on the interpretation of controversial issues: Evaluating evidence and concluding." [In Japanese.] *Journal of Educational Psychology* 52(2): 186-198. doi: 10.5926/jjep1953.52.2_186

Kanda, H., Sugaya, N., Takahashi, K., Mizushima, S., and Koyama, K. 2013. "General workers living with younger children in Fukushima performed more preventive behavior against radiation during and after the nuclear disaster." *Asian Pacific Journal of Cancer Prevention,* 14(11): 6893-6897. doi: 10.7314/APJCP.2013.14.11.6893

Kenny, D. A. (2005). "Cross-lagged panel design". In *Encyclopedia of statistics in behavioral science*, Vol. 1, edited by BS. Everitt, D.C. Howell, 450-451, New York: John Wiley.

Kudo, D. and Nakayachi, K. 2014. "Reputational risk caused by the Great East Japan Earthquake: A study on consumer factors leading to restrained buying". [In Japanese.]

Japanese Journal of Social Psychology, 32(1): 10-21. doi: 10.14966/jssp.30.1_35

Kusumi, T., Hirayama, R., and Kashima, Y. 2017. “Risk perception and risk talk: The case of the Fukushima Daiichi nuclear radiation risk.” *Risk Analysis* 37(12): 2305-2320. doi: 10.1111/risa.12784

Miller, J. D. 1998. The measurement of civic scientific literacy. *Public Understanding of Science* 7(3): 203-223. doi:10.1088/0963-6625/7/3/001

Miura, A., Kusumi, T., and Ogura, K. 2016. “Four-wave panel survey on attitudes towards foodstuffs from areas contaminated by the Fukushima Daiichi nuclear disaster.” [In Japanese.] *Japanese Journal of Social Psychology* 32(1): 10-21. doi: 10.14966/jssp.0928

Nakayachi, K., Yokoyama, H. M., and Oki, S. 2015. “Public anxiety after the 2011 Tohoku earthquake: Fluctuations in hazard perception after a catastrophe.” *Journal of Risk Research,* 18(2): 156-169. doi: 10.1080/13669877.2013.875936

Nakayama, C., Sato, O., Sugita, M., Nakayama, T., Kuroda, Y., Orui, M.,Iwasa, H., Yasumura, S. and Rudd, R. 2019. Lingering health-related anxiety about radiation among Fukushima residents as correlated with media information following the accident at Fukushima Daiichi Nuclear Power Plant. *PLoS One,* 14(5), e0217285. doi:10.1371/journal.pone.0217285

Paakkari, L., and Okan, O. 2020. “COVID-19: Health literacy is an underestimated problem.” *The Lancet Public Health,* 5(5): e249-e250. doi: 10.1016/S2468-2667(20)30086-4

Poumadère, M. and Mays, C. 2014. “Fukushima for you and me ? :Contending with the social disruption caused by a nuclear accident.” *Journal of Nuclear Research and Development* No.8:3-10.

Roozenbeek, J., Schneider, C. R., Dryhurst, S., Kerr, J., Freeman, A. L., Recchia, G., Van Der Bles, A, M., and Van Der Linden, S. 2020. “Susceptibility to misinformation about COVID-19 around the world.” *Royal Society Open Science,* 7(10): 201199. doi: 10.1098/rsos.201199

Ryu, Y., and Kim, S. 2015. “Testing the heuristic/systematic information-processing model (HSM) on the perception of risk after the Fukushima nuclear accidents”. *Journal of Risk Research* 18(7): 840-859. doi: 10.1080/13669877.2014.910694

Schulze, W., and Wansink, B. 2012. “Toxics, Toyotas, and terrorism: The behavioral economics of fear and stigma.” *Risk Analysis*, 32(4): 678-694. doi: 10.1111/j.1539-6924.2011.01748.x

Sloman, S. A. 1996. “The empirical case for two systems of reasoning.” *Psychological Bulletin,*119:3–22. doi: 10.1037/0033-2909.119.1.3

Slovic, P. 1987. “Perception of risk.” *Science,* 236: 280–285. doi: 10.1126/science.3563507

Sugimoto, T., Shinozaki, T., Naruse, T., and Miyamoto, Y. 2014. “Who was concerned about radiation, food safety, and natural disasters after the Great East Japan earthquake and Fukushima catastrophe? A nationwide cross-sectional survey in 2012.” *PloS One,* 9(9), e106377. doi: 10.1371/journal.pone.0106377

Takebayashi, Y., Murakami, M., Nomura, S., Oikawa, T., and Tsubokura, M. 2020. “The trajectories of local food avoidance after the Fukushima Daiichi nuclear plant disaster: A five-year prospective cohort study.” *International Journal of Disaster Risk Reduction* 46: 101513. doi:10.1016/j.ijdrr.2020.101513

Tateno, S., and Yokoyama, H. M. 2013. “Public anxiety, trust, and the role of mediators in communicating risk of exposure to low dose radiation after the Fukushima Daiichi Nuclear Plant explosion.” *Journal of Science Communication* 12(2): A03. doi: 10.22323/2.12020203

Walker, V. 2013. “Defining and identifying "stigma".” In *Risk, media, and stigma: Understanding public challenges to modern science and technology*, edited by Paul Slovic, James Flynn, Howard Kunreuther, 369-376. Abingdon: Routledge.

World Health Organization. 1990. Working Group on the psychological consequences of nuclear accidents (Chernobyl contaminated territories in Ukraine), ed. by J.I. Waddington, Report EUR/ICP/CEH 093(S). Copenhagen: World Health Organization. European Regional Office.

World Health Organization. 2013. *Health risk assessment from the nuclear accident after the 2011 Great East Japan earthquake and tsunami, based on a preliminary dose estimation*. World Health Organization. http://apps.who.int/iris/bitstream/10665/ 78218/1/9789241505130_eng.pdf.

Yoshioka, T., and Maeda, Y. 2020. "COVID-19 stigma induced by local government and media reporting in Japan: It's time to reconsider risk communication lessons from the Fukushima Daiichi nuclear disaster." *Journal of Epidemiology* 30(8):372-373. doi: 10.2188/jea.JE20200247

Yumiya, Y., Murakami, M., Takebayashi, Y., Suzuki, S., and Ohira, T. 2019. "Unreliable information as a risk factor for worse mental fatigue among residents in Fukushima after the nuclear power station accident." *The Tohoku Journal of Experimental Medicine* 248(4): 261-272. doi:10.1620/tjem.248.261

Table 1. Descriptions of questionnaire items

Risk perception of radioactive food contamination

Anxiety related to radioactive contamination (ANX)

- I'm very worried about the effects of radioactive materials released from the Fukushima Dai-ichi nuclear power plant.
- When I buy food, I'm concerned about whether or not radioactive materials have contaminated it.

Active information-seeking behavior (INF)

- I don't believe the information provided by TV or newspapers as is, and I check with other TV programs, newspapers, and the Internet.
- Every day I proactively collect information about the risks of radioactive materials in food, including agricultural and marine products.
- It bothers me when there is something that I don't know about food safety from radioactive materials.

Food avoidance (AVO)

- I don't want to eat food from areas contaminated by radioactive materials, even if the concentration of contamination is below the safety standard.
- I think it is OK to eat food if the concentration of contamination is below the safety standard. (reversed item)

Knowledge of radiation

Knowledge about the health effects of radiation

- Effects of radioactive materials on the human body
- Health effects of artificial radiation and natural radiation
- Long-term health effects

Knowledge of radiation physics

- Sievert and becquerel
- Properties of iodine
- Microgram units

Subjective knowledge of radiation

- Short-term adverse effects of radiation on the human body
- Long-term adverse effects of radiation on the human body
- Methods of decontaminating radioactive materials on clothes
- Methods of decontaminating radioactive materials on vegetables
- Points with high radioactive contamination (hot spots)
- Radioactive contamination of food
- Radioactive contamination of tap water
- Radioactive contamination of soil
- Operational status of nuclear power plants in each region, and the share of nuclear power in total power generation

Information credibility [Subscales]

- Press Conference by the Government [Goverment]
- Public Relations by Government [Goverment]
- Press Conference by Government [Goverment]
- Official website of the government [Goverment]
- Press conference by power companies
- Public relations by power companies
- Television news (factual information only) [Mass media]
- TV information programs (with commentators)
- Newspapers [Mass media]
- Weekly magazine articles that reassure readers
- Weekly magazine articles about the dangers
- Specialists (e.g., university professors) explaining the dangers in a reassuring manner
- Specialists (e.g., university professors) explaining that there are dangers
- Websites managed by the general public [Citizen's websites and word of mouth]
- Word of mouth from someone you know [Citizen's websites and word of mouth]
- Other sources of information (if any)

Table 2. Correlations and means(SDs) of radiation risk perception variables at Time 1 (6 months) and Time 10(9 years)

9 years (n= 423) / 6 months (n=1752)	α	Age	Area of residence	Anxiety (ANX)	Active information-seeking (INF)	Food Avoidance (AVO)	Critical thinking attitude (CT)	Literacy: Media	Literacy: Science	Knowledge: Radiation health effects	Knowledge: Radiation physics	Knowledge: Subjective knowledge	Information credibility: Govern ment	Information credibility: Mass media	Information credibility: Citizen webcite and buzz
Age			-.04	-.01	.06	-.14 **	.07	.04	.09	.04	-.01	.09	-.03	.08	.04
Area of residence (Distance from the plant)[a]		-.01		.08	-.04	.12 **	.01	-.04	-.05	-.09	-.04	-.15 **	-.08	-.08	.11 *
Anxiety related to radioactive contamination (ANX)	.71	-.01	-.08 ***		.54 ***	.43 ***	.10 *	.20 ***	.09	-.12 **	.05	.23 ***	-.23 ***	-.07	.14 **
Active information-seeking behavior (INF)	.68	.03	-.13 ***	.60 ***		.22 ***	.23 ***	.32 ***	.11 *	.01	.10	.43 ***	-.07	-.05	.26 ***
Food avoidance of affected area (AVO)	.73	-.04	.06 **	.56 ***	.41 ***		-.13 **	-.10 *	-.20 ***	-.27 ***	-.12 **	-.13 **	-.17 ***	-.16 ***	.19 ***
Critical thinking attitude (CT)	.91	.03	.00	.18 ***	.33 ***	.04		.36 ***	.32 ***	.21 ***	.19 ***	.25 ***	.00	.12 **	-.06
Literacy:Media	.79	.03	-.08 **	.20 ***	.43 ***	.09 ***	.34 ***		.30 ***	.21 ***	.19 ***	.24 ***	-.07	-.15 **	-.01
Science	.84	.08 ***	-.08 ***	.14 ***	.27 ***	.03	.32 ***	.30 ***		.38 ***	.29 ***	.28 ***	-.03	.07	-.07
Knowledge: radiation health effects	.22	.10 ***	-.04	-.05 *	-.03	-.11 ***	.10 ***	.03	.19 ***		.33 ***	.19 ***	.10 *	.10 *	-.15 **
radiation physics	.24	.05 *	-.12 ***	.09 ***	.19 ***	.02	.17 ***	.16 ***	.28 ***	.19 ***		.30 ***	.03	.08	-.07
subjective knowledge of radiation	.93	.10 ***	-.20 ***	.20 ***	.42 ***	.05 *	.28 ***	.28 ***	.41 ***	.19 ***	.34 ***		.06	.05	.13 **
Information credibility: government	.96	-.01	.05	-.27 ***	-.25 ***	-.22 ***	-.08 ***	-.28 ***	-.10 ***	.08 ***	-.06 *	-.10 ***		.42 ***	.06
mass media	.81	.04	.02	-.11 ***	-.21 ***	-.16 ***	-.02	-.31 ***	-.04	.09 ***	-.02	-.05 *	.50 ***		-.01
citizen webcite and word of mouth	.78	-.01	.02	.17 ***	.15 ***	.17 ***	-.05	.00	-.05 *	-.09 ***	-.07 **	.02	-.07 **	.03	
M(SD) 6 months		44.22 (9.59)	.99 (.84)	3.63 (.96)	3.25 (.77)	2.83 (1.02)	3.59 (.62)	3.54 (.72)	.64 (.31)	.29 (.27)	.47 (.31)	3.06 (.83)	2.24 (.87)	2.98 (.82)	2.60 (.83)
9 years		52.70 (9.57)	1.00 (.82)	2.96 (.88)	2.87 (.66)	2.70 (.82)	3.52 (.65)	3.39 (.75)	.55 (.37)	.39 (.33)	.39 (.32)	2.63 (.81)	2.61 (.87)	3.04 (.71)	2.63 (.73)
t (422)		-348.68 ***	-1.09	14.00 ***	10.48 ***	2.58 ***	2.44 ***	3.89 ***	5.14 ***	-5.42 ***	4.54 ***	10.46 ***	-7.53 ***	-1.67	-.57
d_{Diff}		19.80	.05	.68	.51	.13	.12	.19	.25	.26	.22	.51	.37	.08	.03

Note: [a]Distance from the Fukushima Dai-ichi nuclear power plant: 1=affected area, 2=Tokyo Metropolita Area, 3=Kansai area

*:p<.05, **:p<.01, ***:p<.001

Table 3. Regression Analysis Summary for Predicting Food Avoidance of Affected Areas: Standardized Partial Correlation Coefficients

Predictor variables	6m	1 y	2 y	3 y	4 y	5 y	6 y	7 y	8 y	9 y	8 y(new)
(N)	(1752)	(1474)	(1052)	(864)	(698)	(504)	(458)	(461)	(441)	(423)	(1800)
Age	-.06 **	-.05	-.10 **	-.04	-.04	-.10 *	-.13 **	-.07	-.13 **	-.14 **	-.05 *
Child (0=none, 1=1 or more)	.08 ***	.08 **	.11 ***	.08 *	.08 *	.01	.10 *	.10 *	.18 ***	.11 *	-
Area of residence(Distance from the plant)[a]	.06 *	.10 ***	.11 ***	.10 **	.10 **	.04	.08	.06	.10 *	.12 *	.08 ***
AdjustedR^2 =	.01	.01	.03	.02	.01	.01	.04	.01	.05	.04	.01
Age	-.04 *	-.02	-.07 *	-.03	-.05	-.09 *	-.12 **	-.01	-.08	-.12 **	-.03
Child (0=none, 1=1 or more)	.04 *	.05 *	.07 *	.04	.05	-.02	.03	.05	.13 ***	.10 *	-
Area of residence(Distance from the plant)[a]	.10 ***	.13 ***	.14 ***	.13 ***	.13 ***	.07	.08 *	.03	.10 *	.09 *	.10 ***
Anxiety(ANX)	.57 ***	.53 ***	.51 ***	.54 ***	.51 ***	.49 ***	.49 ***	.53 ***	.47 ***	.43 ***	.52 ***
Critical thinking attitude(CT)	-.05 **	-.07 ***	-.14 ***	-.12 ***	-.15 ***	-.10 **	-.17 ***	-.19 ***	-.21 ***	-.17 ***	-.16 ***
Anxiety(ANX) × Critical thinking attitude(CT)	.07 ***	.07 **	.05	.05	.06	.13 ***	.04	.06	-.07	.01	.06 **
AdjustedR^2 =	.33	.30	.28	.31	.28	.29	.30	.31	.29	.23	.27
R^2 Change F =	281.19 ***	196.93 ***	125.70 ***	125.51 ***	88.44 ***	66.95 ***	55.54 ***	65.56 ***	49.46 ***	36.69 ***	218.96 ***

Note : [a]Distance from the Fukushima Dai-ichi nuclear power plant: 1=affected area, 2=Tokyo Metropolita Area, 3＝Kansai area

*:p<.05, **:p<.01, ***:*p* <.001

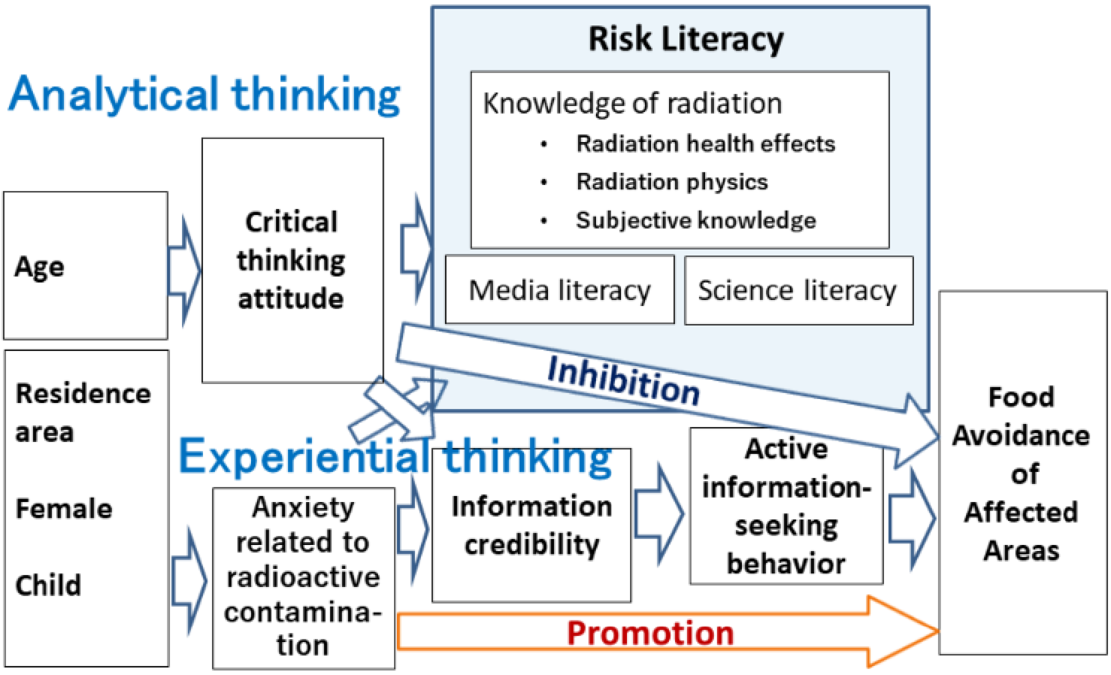

Figure 1. Conceptual framework of food avoidance determinants in the area affected by the Fukushima Dai-ichi nuclear plant accident.

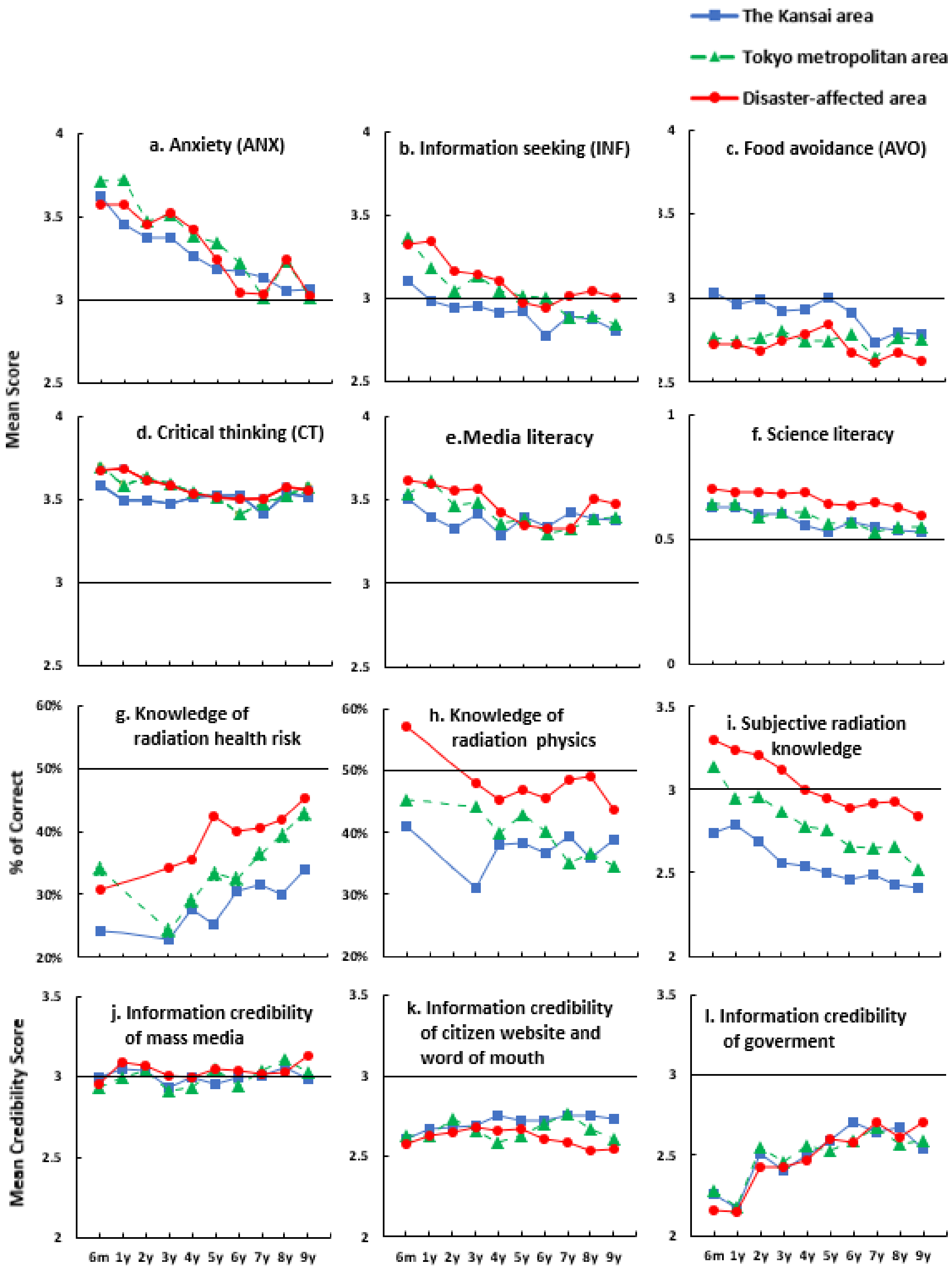

Figure 2. Time-series changes and regional differences in main indices (a-e, i-k: 5-point scales; horizontal lines designate scale midpoints)

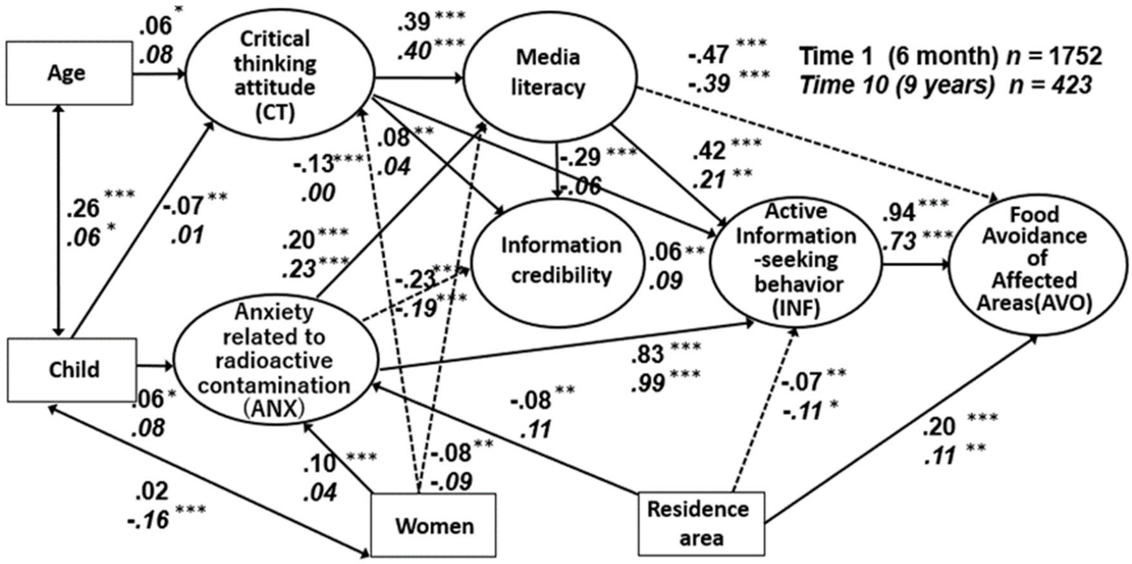

Figure 3. Results of structural equation modeling of factors affecting food avoidance: Numerical values are standardized partial regression coefficients. Anxiety, critical thinking attitudes, media literacy, information credibility, active information-seeking behavior, and food avoidance are latent variables. The covariances between the error variables of the item within each latent factor are set according to the modification index. Measurement variables and error terms of latent variables are omitted to simplify the display.

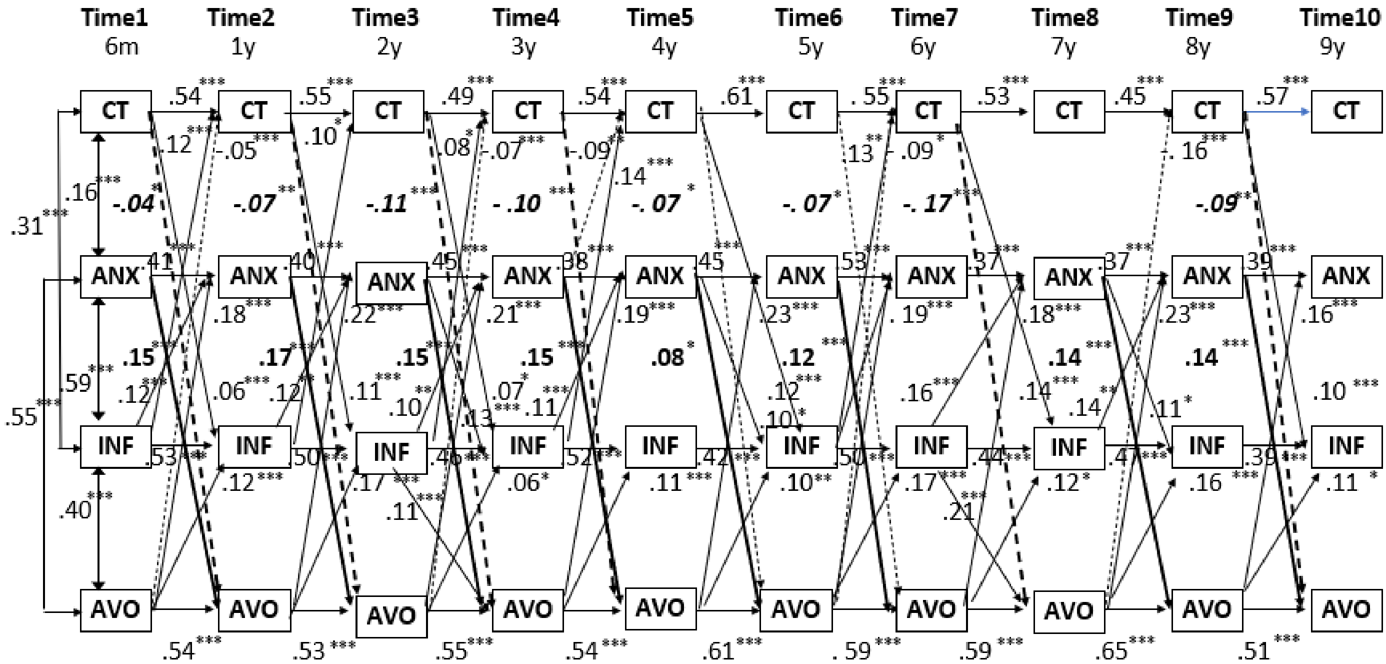

Figure 4. Time-series changes in determinants of local food avoidance using ten-wave cross-lagged model. Numerical values represent standardized partial regression coefficients (CT=Critical thinking attitude, ANX=Anxiety related to radioactive contamination, INF=active information-seeking behavior, AVO=food avoidance of affected area). Error terms of observation variables are omitted to simplify the display.

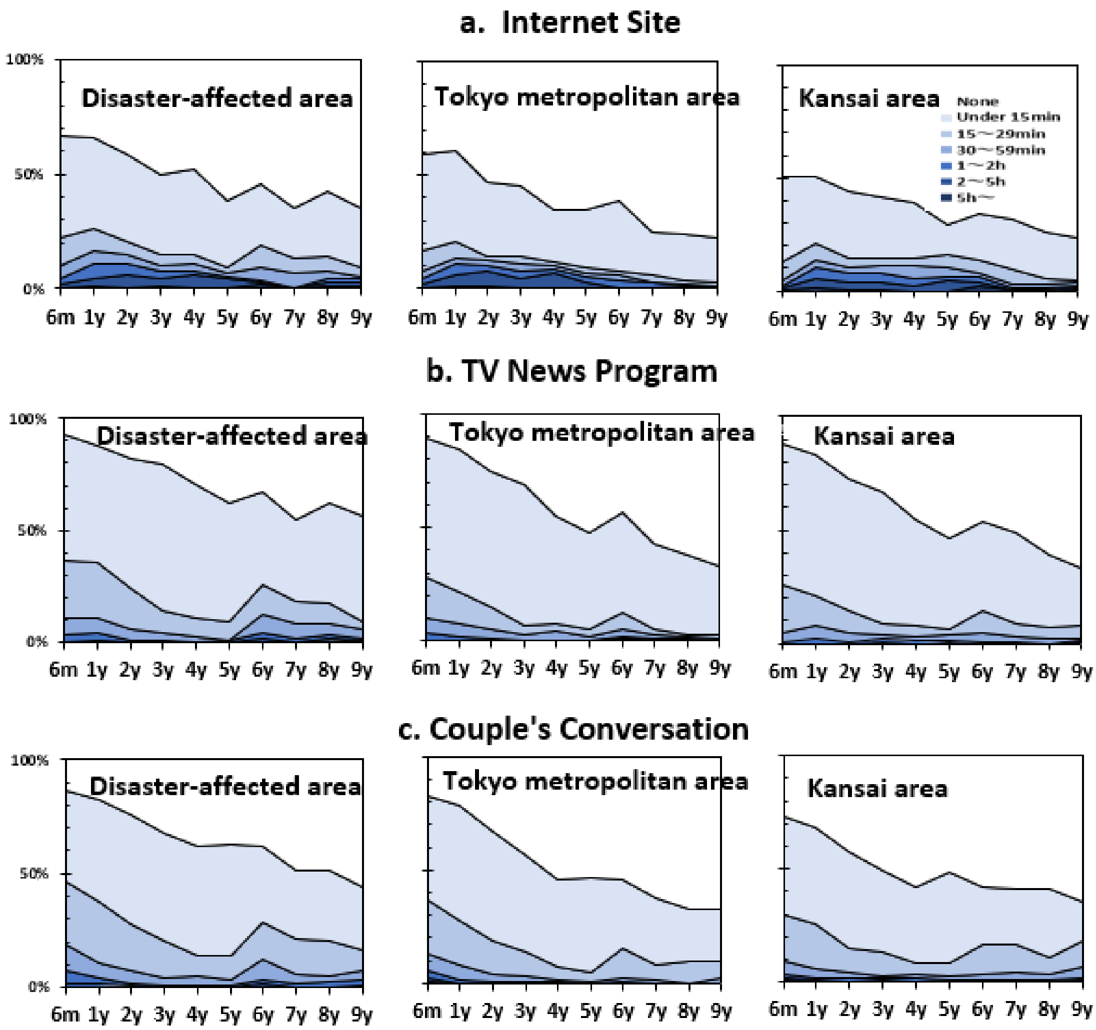

Figure 5. Activities performed to gather information about nuclear disasters, radiation doses, and radiation health effects in one week: (a) time spent using the Internet, (b) time spent watching TV news, (c) time talking with one's partner (evaluated on seven-point response scales).

Appendix A

Preliminary analyses

Of the 1752 participants who participated in the first wave, 24.1% (n = 423) responded to the tenth wave (referred to henceforward as the remaining panel), and 14.7% (n = 258) participants responded to all ten waves (Table 3). Differences between the remaining panel and the dropout panel (n = 1329) were investigated by examining demographic variables and indicated that the remaining rate of men (27%) was slightly higher than that of women (22%; $\chi2(1) = 5.76$, $p=.02$). Participants in the remaining panel did not differ by residential area: disaster-affected area (26%), Tokyo Metropolitan area (22%), and Kansai area (25%) ($\chi2\ (2) = 2.92$, $p=.23$). Mean age was higher for the remaining panel than for dropouts (Ms = 44.1 and 38.8, respectively, $t(768.1) = 9.78$, $p<.001$). Differences between the remaining panel and dropouts were not significant for the 12 leading indices examined in this study: anxiety, active information-seeking behavior, food avoidance, critical thinking attitudes, media literacy, scientific literacy, effects of radiation on the human body, scientific knowledge, subjective knowledge of radiation, and information credibility (government, mass media, and citizen’s websites/word of mouth).

There were significant differences in the mean values of a few items related to knowledge and literacy of the remaining sample, which was higher than the new sample, although the effect sizes were small. Analysis of questions on knowledge about radiation effects on the human body, and science literacy, indicated that the mean correct response rate and the mean ratio of Know responses were higher in the remaining panel (Mkowledges=.37, .36; Mliteracys=.63,.58) than in new samples (Mkowledges=.27, 24; Mliteracys=.56, .50) from the affected area and the Tokyo Metropolitan area (Cohen's dkowledges= 0.34, 0.45; dliteracys = 0.21, 0.22). Moreover, analysis of questions about knowledge of radiation physics and media literacy indicated that the mean correct response rate (Ms=.39, .32) and the mean rating value (Ms = 3.40, 3.23) were higher in the eighth-year samples than in new samples from the Tokyo Metropolitan area (Cohen's ds = 0.23, 0.22).

A new sample (Ns = 1800, 900 men and 900 women In their 20s-50s, all with children and living in the three areas described above) was sampled eight years after the accident as a control group, and mean values were compared with the data of the remaining panel. The new sample and the remaining panel had nearly identical demographic characteristics, except that having children was set as a pre-condition of the new sample. The analysis indicated no significant differences in eight of the 12 indices.

Appendix B: Table B1: Credibility ratings of information sources on radiation

Information source	Affected area (Fukushima, Miyagi, Iwate)										
Time after the accident	6m	1y	2y	3y	4y	5y	6y	7y	8y	9y	8y (New)
Scientists explaining risks	3.1	3.1	2.9	3.0	2.8	2.8	3.0	2.9	2.8	2.9	3.0
Newspaper	3.0	3.1	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.1	3.1
TV news	2.9	3.1	3.1	3.0	3.0	3.1	3.1	3.0	3.0	3.2	3.1
Citizen website	2.6	2.6	2.6	2.7	2.6	2.7	2.5	2.5	2.3	2.4	2.6
Word of mouth	2.6	2.6	2.7	2.7	2.7	2.7	2.7	2.7	2.6	2.7	2.7
Scientists explaining safety	2.5	2.5	2.6	2.7	2.6	2.6	2.7	2.6	2.5	2.8	2.7
Weekly magazine warning risks	2.3	2.7	2.5	2.7	2.6	2.6	2.6	2.5	2.6	2.7	2.7
Governmentwebsite	2.2	2.2	2.5	2.5	2.5	2.7	2.6	2.8	2.7	2.8	2.6
Government public relations	2.1	2.1	2.4	2.4	2.4	2.5	2.6	2.7	2.6	2.6	2.5
Government press conference	2.1	2.1	2.4	2.4	2.4	2.5	2.5	2.7	2.5	2.7	2.5
Weekly magazine reassuring readers	2.0	2.1	2.1	2.2	2.2	2.3	2.3	2.3	2.3	2.4	2.3

Information source	Tokyo Metropolitan area (Tokyo, Saitama, Chiba, Kanagawa)										
Time after the accident	6m	1y	2y	3y	4y	5y	6y	7y	8y	9y	8y (New)
Scientists explaining risks	3.1	3.1	3.0	2.9	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Newspaper	3.0	3.0	3.0	2.9	3.0	3.0	3.0	3.1	3.0	3.0	3.1
TV news	2.9	2.7	3.1	3.0	2.9	3.1	2.9	3.0	3.2	3.0	3.1
Citizen website	2.6	2.7	2.7	2.6	2.6	2.6	2.7	2.7	2.6	2.5	2.6
Word of mouth	2.6	2.6	2.7	2.7	2.6	2.6	2.7	2.8	2.7	2.7	2.7
Scientists explaining safety	2.5	2.6	2.6	2.6	2.5	2.7	2.7	2.7	2.8	2.7	2.7
Weekly magazine warning risks	2.6	2.7	2.6	2.6	2.7	2.8	2.8	2.8	2.8	2.6	2.7
Governmentwebsite	2.3	2.3	2.6	2.5	2.5	2.6	2.6	2.7	2.6	2.6	2.6
Government public relations	2.3	2.1	2.5	2.4	2.4	2.5	2.6	2.7	2.6	2.5	2.5
Government press conference	2.2	2.1	2.5	2.4	2.4	2.5	2.5	2.7	2.5	2.3	2.5
Weekly magazine reassuring readers	2.1	2.1	2.2	2.2	2.2	2.2	2.3	2.4	2.3	2.2	2.3

Information source	Kansai area （Kyoto, Osaka, Hyogo）										
Time after the accident	6m	1y	2y	3y	4y	5y	6y	7y	8y	9y	8y (New)
Scientists explaining risks	3.0	3.0	2.9	2.9	3.0	2.9	2.9	3.0	3.0	3.0	3.0
Newspaper	3.0	3.0	3.0	2.9	3.0	3.0	3.0	3.0	3.0	3.0	3.1
TV news	3.0	3.1	3.0	3.0	3.1	3.0	3.0	3.1	3.1	3.1	3.1
Citizen website	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.8	2.6	2.7	2.6
Word of mouth	2.6	2.6	2.7	2.7	2.8	2.8	2.8	2.7	2.8	2.7	2.7
Scientists explaining safety	2.6	2.6	2.6	2.7	2.6	2.7	2.7	2.7	2.8	2.6	2.7
Weekly magazine warning risks	2.7	2.6	2.6	2.7	2.7	2.6	2.7	2.7	2.6	2.7	2.7
Governmentwebsite	2.3	2.2	2.6	2.4	2.5	2.7	2.7	2.7	2.7	2.7	2.6
Government public relations	2.3	2.2	2.5	2.4	2.5	2.6	2.7	2.6	2.7	2.6	2.5
Government press conference	2.3	2.1	2.5	2.4	2.5	2.6	2.7	2.7	2.7	2.5	2.5
Weekly magazine reassuring readers	2.1	2.1	2.2	2.1	2.3	2.3	2.3	2.3	2.3	2.3	2.3

Note. 5-point scale (1=*Not credible,* 5=*Credible*)