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Long-Term Associations between Disaster-Related Home Loss and Health and Well-Being of Older Survivors: Nine Years after the 2011 Great East Japan Earthquake and Tsunami

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Background: Little research has examined associations between disaster-related home loss and multiple domains of health and well-being, with extended long-term follow-up and comprehensive adjustment for pre-disaster characteristics of survivors.

Objectives: We examined the longitudinal associations between disaster-induced home loss and 34 indicators of health and well-being, assessed ∼9 y post-disaster.

Methods: We used data from a preexisting cohort study of Japanese older adults in an area directly impacted by the 2011 Japan Earthquake ($n = 3{,}350$ and $n = 2{,}028$, depending on the outcomes). The study was initiated in 2010, and disaster-related home loss status was measured in 2013 retrospectively. The 34 outcomes were assessed in 2020 and covered dimensions of physical health, mental health, health behaviors/sleep, social well-being, cognitive social capital, subjective well-being, and prosocial/altruistic behaviors. We estimated the associations between disaster-related home loss and the outcomes, using targeted maximum likelihood estimation and SuperLearner. We adjusted for pre-disaster characteristics from the wave conducted 7 months before the disaster (i.e., 2010), including prior outcome values that were available.

Results: After Bonferroni correction for multiple testing, we found that home loss (vs. no home loss) was associated with increased posttraumatic stress symptoms (standardized difference = 0.50; 95% CI: 0.35, 0.65), increased daily sleepiness (0.38; 95% CI: 0.21, 0.54), lower trust in the community (−0.36; 95% CI: −0.53, −0.18), lower community attachment (−0.60; 95% CI: −0.75, −0.45), and lower prosociality (−0.39; 95% CI: −0.55, −0.24). We found modest evidence for the associations with increased depressive symptoms, increased hopelessness, more chronic conditions, higher body mass index, lower perceived mutual help in the community, and decreased happiness. There was little evidence for associations with the remaining 23 outcomes.

Discussion: Home loss due to a disaster may have long-lasting adverse impacts on the cognitive social capital, mental health, and prosociality of older adult survivors. https://doi.org/10.1289/EHP10903

Introduction

Beyond the risk of immediate injuries and loss of life, disasters are often associated with long-term adverse impacts on the health and well-being of survivors. Disaster survivors suffer not only the lingering effects of traumatic stress but also disruptions in their social circumstances that can have knock-on effects on health.[1] Much like other disaster-related traumatic events (e.g., personal injuries, loss of loved ones), disaster-related property damage may cause prolonged psychological distress; yet, the latter may also have unique impacts on survivors' health because home loss often involves post-disaster displacement. For example, post-disaster displacement can disrupt existing communities and social networks,[2] change one's local neighborhood environment,[3] and increase social isolation,[4] all of which could affect the health and well-being of survivors.[5] Moreover, temporary shelters for survivors are often equipped with cramped kitchen facilities, which may nudge people away from preparing healthy meals at home[6] and increase their reliance on convenient types of meals (e.g., prepackaged meals) that are often calorie-dense and processed.[7] Epidemiologic studies show that disaster-related home loss is associated with increased subsequent mental health problems,[8] functional limitations,[9] and cognitive impairment,[10] as well as worsening cardiometabolic profiles[11] and subjective well-being of survivors.[12]

Although these past epidemiologic studies revealed important insights about the potential long-term impacts of disasters on health and well-being, two knowledge gaps exist. First, health is a multidimensional construct defined as "a state of complete physical, psychological, and social well-being" rather than the mere absence of diseases[13]; nonetheless, prior quantitative studies on health impacts of disasters have generally reported on one or a narrow set of outcomes in a single domain of health and well-being, most often mental health, at a time.[1] Assessing

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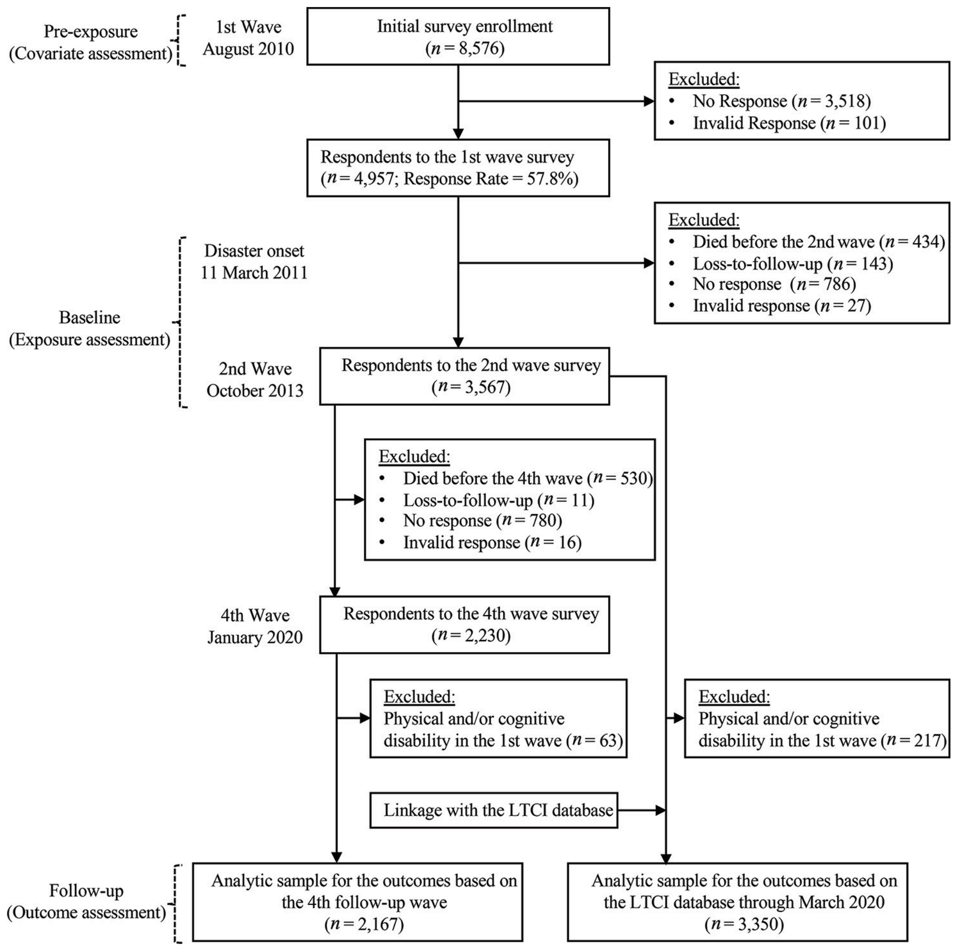

Figure 1. Flow of samples selection. Note: LTCI, long-term care insurance.

outcomes across multiple domains simultaneously would provide a more holistic account of the complex interplay between disaster-related trauma and well-being. For example, although major disasters are generally linked to worsening mental health, some evidence suggests that prosocial behaviors, which capture a key domain of multidimensional well-being,[14] may increase after experiencing traumatic events for some survivors; but more research is needed because evidence in this area is mixed and inconclusive.[15] Second, there is the need for studies with both extended long-term follow-up of survivors and rigorous confounding adjustment. Disaster researchers typically collect data after disasters and often lack information on survivors' characteristics preceding the disaster. Thus, it is not always possible to adjust for potential confounding in the association between disaster-related traumatic events (e.g., property damage, loss of loved ones) and long-term outcomes by survivors' pre-disaster characteristics. Several epidemiologic studies have taken advantage of natural experiment designs in which disasters impacted prospective cohorts that were already in progress, thereby allowing for control of a comprehensive set of pre-disaster information. Such epidemiologic studies have documented persistent associations between disaster-related traumas and increased risk of cognitive decline[16] and posttraumatic stress symptoms (PTSS) 2–5 y after the disaster.[17] Although evidence with longer follow-up controlling for pre-disaster information exists for younger survivors (e.g., increased PTSS 12 y after Hurricane Katrina)[18], such studies are lacking for older disaster survivors—a potentially vulnerable population in the wake of disasters because of factors that could hinder their post-disaster recovery capacity, including impaired physical mobility, diminished sensory awareness, age-related cognitive decline, chronic health conditions, and social limitations.[19]

To address these gaps, the present study leveraged a unique natural experiment setting, wherein a cohort study of older adults established before the 2011 Great East Japan earthquake provided an opportunity to use a rich set of pre-disaster data among survivors. We examined longitudinal associations between disaster-related home loss and a comprehensive array of subsequent health and well-being outcomes assessed up to 9 y after the disaster, including indicators of physical health, health behaviors/sleep, mental health, social well-being, cognitive social capital (i.e., one's perceptions about social relations in the community), subjective well-being, and prosocial/altruistic behaviors.

Methods

Data

We used data from the Iwanuma Study, part of the Japan Gerontological Evaluation Study—a nationwide cohort study of Japanese older adults. Iwanuma City was one of the field sites of the parent cohort study located in Miyagi Prefecture (population size = 44,187 in 2010), ~80 km (128 miles) from the epicenter of the 2011 Great East Japan Earthquake (Figure S1). Importantly, the initial survey of the Iwanuma Study was conducted in August 2010, 7 months before the disaster onset, which enabled us to collect extensive information on the characteristics of disaster survivors predating the event. In the initial survey, a census was taken of all residents ≥65 years of age resident in Iwanuma City ($n = 8{,}576$), yielding valid responses from 4,957 residents (response rate = 57.8%).

The Great East Japan Earthquake (moment magnitude scale: 9.1) occurred on 11 March 2011. The earthquake and subsequent tsunami caused devastating damage to the city of Iwanuma. In Iwanuma, the tsunami killed 180 residents, damaged 5,542 houses, and inundated 48% of the land area in Iwanuma.[20]

Three follow-up surveys of the respondents who survived the disaster were conducted in 2013, 2016, and 2020. We used the 2013 and 2020 waves in this study. We did not use the 2016 wave because we were interested in the longer-term outcomes assessed in the 2020 wave, and all other variables of interest (i.e., covariates and home loss status) were measured in either the 2010 wave or the 2013 wave. In October 2013 (~2.5 y after the disaster), surviving participants retrospectively reported their disaster-related experiences ($n = 3{,}567$). We obtained information on health and well-being outcomes ~9 y after the disaster from two data sources. Specifically, the participants were linked to the public long-term care insurance (LTCI) database ($n = 3{,}567$; 100% linkage) containing information about their vital status, functional disability, and cognitive disability through March 2020. The fourth survey wave conducted in January 2020 ($n = 2{,}230$) gathered information on all other self-reported outcomes (e.g., depression). After excluding individuals who had physical disability, cognitive disability, or both before the disaster, we obtained the analytic samples ($n = 3{,}350$ for the LTCI registry-based outcomes and $n = 2{,}167$ for the survey-based outcomes). See Figure 1 for the flow chart.

Measures

Housing damage and home loss. Property damage in Iwanuma was objectively assessed by property inspectors to evaluate one's eligibility to the public disaster compensation and classified into five levels of severity: *a*) no damage, *b*) partial, *c*) minor, *d*) major, and *e*) complete destruction. Criteria for each level of property damage are summarized in Table S1. In the 2013 wave, participants reported the result of the objective assessment of property damage due to the 2011 earthquake. We created a binary exposure variable representing complete home loss (1 = "complete destruction" and 0 = "major, minor, partial, or no damage"). We focused on complete home loss as opposed to more granular levels of property damage because we had previously documented that complete home loss was a unique predictor of health deterioration after the disaster.[11,21]

Outcomes. Our outcomes of interest were 34 indicators of health and well-being in 2020, as categorized in following seven domains: *a*) physical health (all-cause mortality and new onset of functional/cognitive disability during the follow-up, physical and cognitive disability levels, no remaining natural teeth, self-rated health, instrumental daily activities of living, and number of chronic conditions); *b*) health behaviors/sleep [physical activity (in metabolic units per week), current smoking, body mass index (BMI; in kilograms per meter squared), daily sleepiness, and insomnia]; *c*) mental health (depressive symptoms, psychological distress, PTSS, and hopelessness); *d*) social well-being (participation in a hobby group, sports group, or senior citizens club, frequency of meeting friends, number of friends seen per month, emotional social support, and care social support); *e*) cognitive social capital (trust, mutual help, and community attachment); *f*) subjective well-being (happiness and life satisfaction); and *g*) prosocial/altruistic behaviors [prosociality (dictator game contribution), volunteering, and sharing skills and experiences]. Table S2 provides further details about each outcome measurement.

Covariates. All preexposure covariates were drawn from the 2010 survey conducted 7 months before the disaster. These covariates were age, gender (men or women), marital status (married, widowed, divorced, single, or other), living alone (yes or no), education (<6, 6–9, 10–12, ≥13 y, or other), job (working, retired, or never worked), equivalized household income, and the number of major life events in the past year. To further reduce the possibility of confounding and reverse causation, we also controlled for pre-disaster values of all outcomes from the 2010 wave, except for the following outcomes that were not measured in 2010: psychological distress, PTSS, physical activity, daily sleepiness, insomnia, happiness, prosociality, and sharing skills and experiences. Pre-disaster values of the LTCI-based outcomes (all-cause mortality and physical/cognitive disability) were controlled by design because we analyzed living individuals who had no pre-disaster physical/cognitive disability.

Statistical Analysis

We used a longitudinal outcome-wide analytic approach, which enables a holistic assessment of the impact that a single exposure has on a wide range of outcomes and has several other methodological advantages (e.g., being less susceptible to *p*-hacking and publication bias).[22] To estimate the associations between home loss and each outcome (adjusted for the covariates and prior outcome values from the preexposure wave), we used doubly robust targeted maximum likelihood estimation.[23] This approach estimates both the exposure (propensity) model and outcome model and yields unbiased estimates for an exposure–outcome association if either of the two models is consistently estimated. Hence, the approach is more robust to model misspecification. This analytic approach was used because we conditioned on many covariates, and a conventional estimation approach using parametric outcome regression would be prone to model misspecification. We conducted even more robust and stable estimation by fitting both exposure and outcome models data-adaptively via SuperLearner, an ensemble method that uses weighted combinations of multiple machine learning algorithms.[24] As candidate estimators for SuperLearner, we used generalized linear models, a gradient boosting machine, and a neural net.[25,26] Targeted maximum likelihood estimation and Super Learning were performed using the *ltmle* and SuperLearner R packages.[27,28] We showed our R code to implement this analysis in the Supplemental Material, "Appendix 1. R code for Targeted Maximum Likelihood Estimation and SuperLearner using the Imputed Data from Multiple Imputation by Chained Equation."

For all-cause mortality and functional/cognitive disability onset, the binary outcomes were the first incidence during the follow-up; hence, we estimated risk ratios for cumulative incidence. For all other binary outcomes, we estimated prevalence ratios. All continuous outcomes were standardized [mean = 0, standard deviation (SD) = 1], so that the effect estimates can be interpreted as a SD change in the outcome variable. We used a Bonferroni correction to account for multiple testing and used $0.05/34$ outcomes $= p < 0.0015$ as a threshold for statistical significance in the outcome-wide analysis. As for the descriptive analysis, we used the conventional $p < 0.05$ threshold. As a post hoc sensitivity analysis, we repeated the same analysis using the alternative cutoff for property damage (i.e., complete loss/major damage vs. minor, partial, or no damage).

To evaluate the robustness of our effect estimates to unmeasured confounding, we calculated E-values for each exposure–outcome association.[29] E-values quantify the minimum strength of association on the risk ratio scale that an unmeasured confounder would need to have with both the exposure and outcome, above and beyond the adjusted covariates, to explain away the observed association.

Table 1. Levels of property damage and preexposure demographic characteristics [n (%) or mean ± SD] stratified by home loss status among the analytic sample for the analysis of the outcomes from the 4th follow-up survey wave conducted in January 2020, Iwanuma, Japan, 2010 ($n = 2,167$).

Characteristics	Overall $n = 2,167$	Home loss status[a] No $n = 2,028$	Home loss status[a] Yes $n = 92$	p-Value[b]
Levels of property damage				<0.001
Complete destruction (home loss)	92 (4.3)	0 (0)	92 (100)	
Major damage	73 (3.4)	73 (3.6)	0 (0)	
Minor damage	147 (6.8)	147 (7.2)	0 (0)	
Partial damage	945 (44)	945 (47)	0 (0)	
No damage	863 (40)	863 (43)	0 (0)	
Missing	47 (2.2)	0 (0)	0 (0)	
Sociodemographic factors				
Age (y)	71.8 ± 5.2	71.8 ± 5.2	71.7 ± 5.3	0.65
Gender				0.96
Men	954 (44)	899 (44)	41 (45)	
Women	1,213 (56)	1,129 (56)	51 (55)	
Marital status				0.45
Married	1,621 (75)	1,524 (75)	69 (75)	
Widowed	418 (19)	389 (19)	15 (16)	
Divorced	48 (2.2)	47 (2.3)	0 (0)	
Single	17 (0.8)	16 (0.8)	0 (0)	
Other	12 (0.6)	11 (0.5)	1 (1.1)	
Missing	51 (2.4)	41 (2.0)	7 (7.6)	
Living alone				0.05
No	1,964 (91)	1,835 (90)	88 (96)	
Yes	161 (7.4)	155 (7.6)	2 (2.2)	
Missing	42 (1.9)	38 (1.9)	2 (2.2)	
Education (y)				<0.001
<6	11 (0.5)	11 (0.5)	0 (0)	
6–9	652 (30)	574 (28)	56 (61)	
10–12	987 (46)	939 (46)	26 (28)	
≥13	459 (21)	453 (22)	4 (4.3)	
Other	12 (0.6)	11 (0.5)	1 (1.1)	
Missing	46 (2.1)	40 (2.0)	5 (5.4)	
Job				0.15
Working	415 (19)	390 (19)	18 (20)	
Retired	1,232 (57)	1,171 (58)	41 (45)	
Never worked	301 (14)	277 (14)	17 (18)	
Missing	219 (10)	190 (9.4)	16 (17)	
Equivalized household income (10,000 yen)	143 ± 89	146 ± 89	101 ± 83	<0.001
Missing	361 (17)	334 (16)	13 (14)	
Life events in the past year (n)	0.91 ± 0.95	0.91 ± 0.96	0.85 ± 0.95	0.51
Missing	116 (5.4)	103 (5.1)	8 (8.7)	
Physical health				
Health conditions (n)	1.48 ± 1.39	1.48 ± 1.38	1.44 ± 1.31	0.85
Missing	45 (2.1)	40 (2.0)	4 (4.3)	
Remaining natural teeth (n)				0.001
At least one remaining natural tooth	1,973 (91)	1,854 (91)	74 (80)	
None	167 (7.7)	151 (7.4)	15 (16)	
Missing	27 (1.2)	23 (1.1)	3 (3.3)	
Good self-rated health				0.90
No	288 (13)	269 (13)	12 (13)	
Yes	1,840 (85)	1,727 (85)	74 (80)	
Missing	39 (1.8)	32 (1.6)	6 (6.5)	
Instrumental activities of daily living	12.11 ± 1.47	12.12 ± 1.48	12.08 ± 1.21	0.20
Missing	92 (4.2)	85 (4.2)	6 (6.5)	
Mental health				
Depressive symptoms	3.3 ± 3.2	3.2 ± 3.2	3.4 ± 2.9	0.22
Missing	247 (11)	226 (11)	14 (15)	
Hopelessness				0.02
No	1,694 (78)	1,603 (79)	62 (67)	
Yes	414 (19)	371 (18)	25 (27)	
Missing	59 (2.7)	54 (2.7)	5 (5.4)	
Health behaviors/sleep				
Current smoker				0.23
No	1,801 (83)	1,697 (84)	70 (76)	
Yes	218 (10)	198 (9.8)	12 (13)	
Missing	148 (6.8)	133 (6.6)	10 (11)	
BMI (kg/m^2)	23.60 ± 2.95	23.56 ± 2.96	24.20 ± 2.57	0.02
Missing	108 (5.0)	90 (4.4)	9 (9.8)	

Table 1. (*Continued.*)

Characteristics	Overall	Home loss status[a]		p-Value[b]
		No	Yes	
	$n = 2{,}167$	$n = 2{,}028$	$n = 92$	
Participating health checkup in the past year				0.06
No	504 (23)	460 (23)	28 (30)	
Yes	1,614 (74)	1,525 (75)	60 (65)	
Missing	49 (2.3)	43 (2.1)	4 (4.3)	
Social well-being				
Frequency of participation in				
Hobby clubs	2.38 ± 1.49	2.40 ± 1.49	1.93 ± 1.31	0.01
Missing	258 (12)	223 (11)	25 (27)	
Sport clubs	1.96 ± 1.48	1.98 ± 1.48	1.55 ± 1.25	0.02
Missing	291 (13)	253 (12)	27 (29)	
Senior clubs	1.38 ± 0.84	1.36 ± 0.82	1.81 ± 1.16	<0.001
Missing	315 (15)	283 (14)	20 (22)	
Frequency of meeting friends	3.79 ± 1.45	3.78 ± 1.44	4.13 ± 1.59	0.02
Missing	59 (2.7)	49 (2.4)	8 (8.7)	
Number of friends I met last month	2.29 ± 1.25	2.29 ± 1.25	2.21 ± 1.23	0.61
Missing	59 (2.7)	45 (2.2)	8 (8.7)	
Emotional social support				0.44
No	104 (4.8)	99 (4.9)	2 (2.2)	
Yes	1,999 (92)	1,873 (92)	84 (91)	
Missing	64 (3.0)	56 (2.8)	6 (6.5)	
Caregiving social support				0.52
No	67 (3.1)	63 (3.1)	1 (1.1)	
Yes	2,065 (95)	1,934 (95)	89 (97)	
Missing	35 (1.6)	31 (1.5)	2 (2.2)	
Cognitive social capital				
Trust in the community	3.77 ± 0.75	3.77 ± 0.74	3.85 ± 0.82	0.18
Missing	33 (1.5)	26 (1.3)	6 (6.5)	
Mutual help in the community	3.55 ± 0.81	3.55 ± 0.81	3.53 ± 0.87	0.84
Missing	43 (2.0)	35 (1.7)	5 (5.4)	
Community attachment	4.01 ± 0.80	4.00 ± 0.80	4.09 ± 0.95	0.10
Missing	36 (1.7)	33 (1.6)	3 (3.3)	
Psychological well-being				
Life satisfaction				0.74
No	436 (20)	408 (20)	17 (18)	
Yes	1,684 (78)	1,579 (78)	72 (78)	
Missing	47 (2.2)	41 (2.0)	3 (3.3)	
Pro-social/altruistic behaviors				
Frequency of volunteering	1.45 ± 0.91	1.44 ± 0.91	1.58 ± 1.00	0.12
Missing	385 (18)	341 (17)	33 (36)	

Note: BMI, body mass index.
[a]Sample sizes for the home loss strata in this table do not add up to the overall sample size ($n = 2{,}167$) because of missing data in the home loss variable.
[b]p-Values were calculated using Pearson's chi-square test for categorical variables and Wilcoxson rank sum test for continuous variables.

We used multiple imputation by chained equations via the *mice* R package[30] to impute missing data on all covariates, outcomes, and exposure. After generating five imputed data sets, we performed the analyses described above using each imputed data set and combined the results across imputations. All analyses were conducted in R (version 3.6.0; R Development Core Team). All procedures involving human participants/patients were approved by the ethics committees of the Harvard T. H. Chan School of Public Health (P23143-101). Written informed consent was obtained from all participants/patients.

Results

Table 1 shows preexposure characteristics of the study sample linked to the fourth survey wave ($n = 2{,}167$), which we used to assess the survey-based outcomes, according to home loss status. Compared with individuals who did not lose their homes, those who experienced home loss reported fewer years of schooling (e.g., ≥13 y: 4.6% vs. 23% among the unexposed), lower household income [101 (10,000 yen) vs. 146 among the unexposed], and more preexposure health problems (e.g., no remaining teeth and higher sense of hopelessness). These trends were also found in the study sample linked to the LTCI database ($n = 3{,}350$; Table S3). Although individuals with home loss reported greater pre-disaster BMI and frequency of meeting friends across the two analytic samples with comparable point estimates (Table 1; Table S3), the associations were below the $p = 0.05$ threshold only in the sample linked to the fourth survey wave (Table 1). Similarly, individuals with home loss reported lower instrumental daily activities of living and greater depressive symptoms across the two samples, but the associations reached the $p = 0.05$ threshold only among the analytic sample linked to the administrative data.

Table 2 shows the estimated standardized differences in the continuous outcomes and risk or prevalence ratios for binary outcomes comparing those with vs. without home loss, controlling for the preexposure covariates and prior outcome values. Approximately 9 y after the disaster, disaster-related home loss was associated with higher PTSS [standardized difference = 0.50; 95% confidence interval (CI): 0.35, 0.65] and daily sleepiness (standardized difference = 0.38; 95% CI: 0.21, 0.54) as well as lower trust in the community (standardized difference = −0.36; 95% CI: −0.53, −0.18), lower community attachment (standardized difference = −0.60; 95% CI: −0.75, −0.45), and lower prosociality (standardized difference = −0.39; 95% CI:

Table 2. Associations between home loss and subsequent health and well-being, Iwanuma, Japan, 2011–2020.

Outcome	β[a,b]	RR/PR[c]	95% CI Lower	95% CI Upper	p-Value[d]
Physical health					
All-cause mortality	—	0.75	0.43	1.29	0.293
Functional disability onset					
≥Level 3	—	1.06	0.80	1.41	0.670
Any level	—	0.97	0.76	1.23	0.809
Level of certified physical disability	−0.002	—	−0.10	0.10	0.961
Cognitive disability onset	—	1.08	0.78	1.49	0.656
Level of certified cognitive disability	0.03	—	−0.06	0.12	0.486
No remaining natural teeth	—	1.30	0.78	2.18	0.312
Good self-rated health	—	0.95	0.81	1.11	0.513
Instrumental activities of daily living	−0.12	—	−0.35	0.10	0.235
Number of chronic conditions	0.21	—	0.00	0.42	0.050
Mental health					
Depressive symptoms	0.17	—	0.05	0.29	0.007
Psychological distress	0.07	—	−0.06	0.21	0.290
Posttraumatic stress symptoms	0.50	—	0.35	0.65	<0.001
Hopelessness	—	1.52	1.02	2.26	0.040
Health behaviors/sleep					
Physical activity	−0.03	—	−0.24	0.18	0.739
Current smoker	—	1.51	0.70	3.24	0.287
BMI	0.13	—	0.01	0.25	0.037
Daily sleepiness	0.38		0.21	0.54	<0.001
Insomnia	−0.08	—	−0.30	0.14	0.442
Social well-being					
Frequency of participation in					
Hobby clubs	0.11	—	−0.03	0.25	0.127
Sport clubs	0.08	—	−0.08	0.23	0.304
Senior clubs	0.00	—	−0.14	0.15	0.975
Frequency of meeting friends	0.04	—	−0.15	0.23	0.653
Number of friends I met last month	−0.06	—	−0.19	0.07	0.365
Emotional social support	—	0.99	0.93	1.06	0.833
Caregiving social support	—	0.99	0.92	1.06	0.743
Cognitive social capital					
Trust in the community	−0.36	—	−0.53	−0.18	<0.001
Mutual help in the community	−0.31	—	−0.52	−0.11	0.005
Community attachment	−0.60	—	−0.75	−0.45	<0.001
Subjective well-being					
Happiness	−0.22	—	−0.36	−0.07	0.005
Life satisfaction	—	0.98	0.88	1.10	0.742
Prosocial/altruistic behaviors					
Prosociality (dictator game contribution)	−0.39	—	−0.55	−0.24	<0.001
Frequency of volunteering	0.19	—	−0.10	0.49	0.172
Frequency of sharing skills and experiences	−0.03	—	−0.18	0.13	0.742

Note: —, not applicable; BMI, body mass index; CI, confidence interval; PR, prevalence ratio; RR, risk ratio; β, standardized difference.
[a]The analytic sample size was $n = 3{,}350$ for the following outcomes: all-cause mortality, functional disabilities, and dementia onset, as well as level of certified physical and cognitive disability. For all other outcomes, the analytic sample size was $n = 2{,}028$.
[b]We estimated standardized differences for the continuous outcomes and RRs/PRs for the binary outcomes, using the doubly-robust targeted maximum likelihood estimation. Models were estimated data-adaptively via SuperLearner using generalized linear mode, a gradient boosting machine, and neural net as candidate estimators. All models were adjusted for pre-exposure covariates (age, gender, marital status, living alone, education, job, equivalized household income, and the number of major life events in the past year) as well as preexposure levels of outcomes wherever data was available to address reverse causation. Preexposure outcome values were available for the following outcomes: the number of health conditions, no remaining natural teeth, good self-rated health, instrumental activities of daily living, current smoker, BMI, depressive symptoms, hopelessness, frequency of social participation (hobby clubs, sport clubs, and senior clubs), frequency of meeting friends, number of friends I met last month, reception of emotional and caregiving social support, life satisfaction, and frequency of volunteering.
[c]For all-cause mortality, functional disability, and dementia, the outcomes were incidence during the follow-up through March 2020 because the individuals in the analytic sample were free from these disability before the disaster; hence, we estimated RRs for cumulative incidence. For all other binary outcomes, we estimated PR of the outcomes reported in the fourth survey wave, January 2020.
[d]The p-value cutoff for the Bonferroni correction is $p = 0.05/34$ outcomes $= p < 0.0015$.

−0.55, −0.24). These associations remained below the $p = 0.05$ threshold after accounting for multiple testing via a Bonferroni correction. There was modest evidence of associations between home loss and more chronic conditions (standardized difference = 0.21; 95% CI: 0.00, 0.42), greater depressive symptoms (standardized difference = 0.17; 95% CI: 0.05, 0.29), more prevalent hopelessness (prevalence ratio = 1.52; 95% CI: 1.02, 2.26), higher BMI (standardized difference = 0.13; 95% CI: 0.01, 0.25), lower perceived mutual help in the community (standardized difference = −0.31, 95% CI: −0.52, −0.11), and lower happiness (standardized difference = −0.22; 95% CI: −0.36, −0.07); however, these additional associations were not below the $p = 0.05$ threshold after the Bonferroni correction. We found little evidence of associations between home loss and other health and well-being outcomes. The results were largely comparable when we used the alternative cutoff for property damage (Table S4).

The calculated E-values (Table 3) suggest that some of the observed associations of home loss and subsequent health and well-being outcomes were moderately robust to an unmeasured confounder. For example, to explain away the association between home loss and greater PTSS (point estimate = 0.50), an unmeasured confounder associated with both home loss and PTSS—above and beyond the adjusted covariates—by

Table 3. Robustness to unmeasured confounding (E-values) of associations between home loss and subsequent health and well-being, Iwanuma, Japan, 2011–2020.

Outcome[a]	E-Value for point estimate[b,c]	E-Value for confidence limit[b,d]
Physical health		
All-cause mortality	2.01	1.00
Functional disability onset		
≥Level 3	1.32	1.00
Any level	1.21	1.00
Level of certified physical disability	1.05	1.00
Cognitive disability onset	1.36	1.00
Level of certified cognitive disability	1.20	1.00
Remaining natural teeth (n)	1.93	1.00
Good self-rated health	1.29	1.00
Instrumental activities of daily living	1.49	1.00
Chronic conditions (n)	1.72	1.13
Mental health		
Depressive symptoms	1.61	1.27
Psychological distress	1.34	1.00
Posttraumatic stress symptoms	2.54	2.11
Hopelessness	2.40	1.16
Health behaviors/sleep		
Physical activity	1.20	1.00
Current smoker	2.39	1.00
BMI	1.50	1.15
Daily sleepiness	2.17	1.76
Insomnia	1.36	1.00
Social well-being		
Frequency of participation in		
Hobby clubs	1.45	1.00
Sport clubs	1.36	1.00
Senior clubs	1.05	1.00
Frequency of meeting friends	1.24	1.00
Number of friends I met last month	1.29	1.00
Emotional social support	1.09	1.00
Caregiving social support	1.12	1.00
Cognitive social capital		
Trust in the community	2.11	1.66
Mutual help in the community	1.99	1.48
Community attachment	2.84	2.40
Subjective well-being		
Happiness	1.73	1.36
Life satisfaction	1.16	1.00
Prosocial/altruistic behaviors		
Prosociality (dictator game contribution)	2.22	1.82
Frequency of volunteering	1.67	1.00
Frequency of sharing skills and experiences	1.18	1.00

Note: BMI, body mass index.
[a]The analytic sample size was $n = 3,350$ for the following outcomes: all-cause mortality, functional disabilities, and dementia onset as well as level of certified physical and cognitive disability. For all other outcomes, the analytic sample size was $n = 2,167$.
[b]For the formulas to calculate E-values, see VanderWeele and Ding (2017).
[c]E-values for effect estimates are the minimum strength of association on the risk ratio scale that an unmeasured confounder would need to have with both the exposure and the outcome, above and beyond the measured covariates, to fully explain away the observed associations of home loss with the outcomes. Measured covariates include preexposure sociodemographic characteristics (age, gender, marital status, living alone, education, job, equivalized household income, and the number of major life events in the past year) as well as preexposure levels of outcomes wherever data was available to address reverse causation. Preexposure outcome values were available for the following outcomes: the number of health conditions, no remaining natural teeth, good self-rated health, instrumental activities of daily living, current smoker, BMI, depressive symptoms measured, hopelessness, frequency of social participation (hobby clubs, sport clubs, and senior clubs), frequency of meeting friends, number of friends I met last month, reception of emotional and caregiving social support, life satisfaction, and frequency of volunteering.
[d]E-values for the 95% confidence interval limit closest to the null denote the minimum strength of association on the risk ratio scale that an unmeasured confounder would need to have with both the exposure and the outcome, above and beyond the measured covariates, to shift the 95% confidence interval to include the null value (i.e., 0 for continuous outcomes and 1 for binary outcomes). For associations that were above the $p < 0.05$ threshold, E-value for confidence limit is 1.

risk ratios of 2.54 each could suffice, but weaker joint confounder associations could not. To fully explain away the CI for the observed association confounding risk ratios of 2.11-fold each could suffice, but weaker joint confounder associations could not.

Discussion

In this longitudinal study of older survivors from the 2011 Great East Japan Earthquake, we examined the associations of disaster-related home loss with subsequent health and well-being over a 9-y follow-up period, adjusting for a comprehensive set of participants' characteristics predating the disaster. We extended prior research that has tended to focus on the impacts of home loss on a narrow set of health and well-being outcomes, typically those limited to the domain of mental health. Our main findings are 3-fold. First, home loss was consistently associated with persistent mental health problems; there was robust evidence for increased PTSS, and somewhat more modest evidence for increased depressive symptoms and risk of hopelessness at the 9-y follow-up point after the disaster. Second, in addition to the mental health outcomes, home loss was associated with broader indices of well-being that prior epidemiologic studies have not examined, including decreased levels of cognitive social capital (trust in the community, community attachment, and perceptions of mutual help in the community), decreased prosociality, and increased daily sleepiness. Third, there was modest evidence linking home loss with increased chronic conditions, higher BMI, and decreased happiness; however, there was little evidence that home loss was associated with other health and well-being outcomes.

Evidence is mixed on the long-term impacts of major disasters on mental health. Our result indicates that property loss might have a long-lasting adverse influence on PTSS (and perhaps depression and hopelessness), even 9 y after the disaster. This finding is consistent with some prior epidemiologic studies documenting lingering associations between property damage and increased PTSS years after disasters[17,31]; in contrast, a 12-y follow-up study of survivors of Hurricane Katrina showed that the association between property damage and PTSS attenuated over time.[18] However, it is notable that these prior epidemiologic studies did not control for (or only minimally controlled for) pre-disaster characteristics of survivors given that such data are rarely available. We extended the previous evidence by leveraging the natural experiment design and adjusted for a comprehensive set of pre-disaster characteristics, including preexposure outcome levels.

One postulated explanation for the potential long-term impacts of home loss on post-disaster psychopathology is prolonged psychological distress. Other types of disaster-related traumatic events, such as losing a loved one, have been linked to psychopathology in other disaster settings[8]; however, a previous study reported that only property damage predicted post-disaster depressive symptoms in Iwanuma after the 2011 Japan Earthquake, whereas other disaster-related traumatic events (e.g., loss of loved ones) did not.[21] This observation lead us to hypothesize that there are additional factors at work that are unique to the situation of victims who experienced home loss in Iwanuma. Accumulating evidence suggests that community social capital—bonds of trust between community members and norms of mutual assistance—plays a key role in promoting disaster resilience and recovery and preventing the onset of PTSS.[32] In Iwanuma, home loss was often followed by post-disaster relocation, disruption of communities and one's social relationships that existed before the disaster, and erosion of social capital.[2] We found modest-to-robust evidence that home loss was associated with decreased levels of perceived social cohesion, even 9 y after the disaster.

There were two occasions of mass relocation in Iwanuma. The first relocation was months after the disaster when survivors gradually moved out of the emergency shelters (e.g., local school's gymnasium) in either of the following two forms: *a*) group relocation, in which whole communities were moved to public prefabricated temporary housing villages (kasetsu jutaku, which resembled Federal Emergency Management Agency trailer parks in the United States), or *b*) individual relocation, in which people were moved to the public temporary housing villages through a random lottery or into subsidized apartments on the private rental market or they built new homes at their own expense. Group relocation may have helped to preserve social connections in the community.[33] A previous epidemiologic study demonstrated that, 2.5 y after the disaster, group relocation likely preserved and even promoted post-disaster informal socializing/social participation in Iwanuma, whereas individual relocation decreased it.[2] However, the same study reported that both group relocation and individual relocation were associated with decreased cognitive social capital. The public prefabricated houses afforded very little privacy from neighbors because of their thin walls, and many suffered from poor insulation during winter.[6,34] Such living conditions may have caused friction between residents of the temporary villages and disrupted cognitive social capital, even among those who experienced group relocation. The second mass relocation occurred when the trailer home village was closed down by the city in April 2016—~ 5 y after the disaster. At this time, residents of the temporary village either *a*) moved to the permanent public housing community built by the city, or *b*) individually rented or built/owned a home outside of the permanent housing community. The latter type of move from temporary housing may have disrupted survivors' social capital even further.[16]

Home loss, subsequent displacement, and erosion of social capital can occur in other disaster settings too (e.g., hurricanes, flooding).[35] Although providing material support for survivors who experienced disaster-related traumatic events will continue to remain important, interventions/policies focused on maintaining social capital among people who experienced post-disaster displacement might facilitate post-disaster recovery. An example of a social capital intervention is the "ibasho cafe"—an initiative developed after the 2011 Japan earthquake to create a community hub managed by older adults and volunteers featuring a café (where people could congregate), a vegetable garden, a farmers' market, a ramen noodle shop, a day care, an evacuation center, and a community resource center where older adults can teach local cultural traditions to younger people.[36] Future studies should empirically investigate whether such post-disaster community building efforts can preserve social capital among evacuees.

We also found some evidence for increased BMI and chronic conditions. Previous epidemiologic studies with shorter follow-up lengths had likewise showed that property loss was associated with deteriorated cardiometabolic profiles of survivors, including BMI.[11] Post-disaster relocation to new homes may explain, at least partly, the association.[37] Relocation may result in loss of social connections, social isolation, and home-bound status, which can lead to decreased opportunities to engage in physical activity. Relocation may also change one's neighborhood environment (e.g., improved proximity to food outlets and more frequent dining out) and affect one's BMI.[3] The cramped kitchen facilities in the trailer homes may have further nudged people away from preparing healthy meals at home.[6] A previous epidemiologic study of the Iwanuma population documented that, although the first relocation was associated with increased BMI, the second relocation did not appear to result in additional impacts on BMI.[16] Hence, it is likely the first, not second, relocation that explains our finding of a persistent associations between home loss and BMI 9 y after the disaster. We also found relatively strong evidence of increased daily sleepiness. Although the underlying mechanism is unclear, taking medication for psychiatric diseases (e.g., depressive symptoms) may explain the association; however, future research should test for this potential mechanism empirically. Moreover, the increased daily sleepiness may be attributable to sleep issues caused by depression and PTSS; however, we found no strong evidence of associations with insomnia.

Home loss was also robustly associated with decreased level of prosociality in this study. Our finding is consistent with prior literature; for example, in the study of survivors from the 2015 Cyclone Pam, greater property damage was associated with decreased levels of experimentally assessed prosociality.[15] Evidence suggests that unpredictable and resource-scarce environments, such as disaster-related home loss, may result in increased preference for immediate (self-centered) gratitude rather than long-term (prosocial) payoffs.[38] However, an alternative theory has also been proposed, predicting the opposite tendency—increased prosociality following traumatic experiences, and some empirical evidence has supported this trend.[39]

In this study, home loss (vs. no home loss) was associated with fewer years of schooling, lower household income, and more health problems before the earthquake. This observation is consistent with the literature, arguing that natural disasters are not random occurrences.[1] The likelihood of the exposure to disaster-related traumatic experiences are likely socially patterned; for example, individuals from lower socioeconomic backgrounds may be at higher risk of experiencing home loss due to the location and quality of housing. In addition to the differential distribution of exposure to home loss, the magnitude of the health effects of home loss may be socially patterned. For example, the adverse effects of home loss on survivors' mental health has been reported to be greater among people with socioeconomically disadvantaged backgrounds because they tend to have fewer resources (e.g., income, social support) that they can mobilize to cope with the stressors.[40] Taken together, disasters and subsequent home loss affect survivors' health on average but also tend to widen social inequalities in health. Thus, highly affected subpopulations need to be considered in planning policies for resilience building and post-disaster responses.[41]

Despite some observed associations discussed above, there was little evidence of associations between home loss and other indices of health and well-being outcomes. For example, emerging evidence from epidemiologic studies with a shorter follow-up has shown that disaster-related trauma may lead to subsequent functional and cognitive decline among older survivors.[10,42] We found that home loss was not associated with any of these outcomes 9 y after the disaster. This pattern of findings may be attributable to aging, given that members of our analytic sample had an average age of 74 y when the disaster occurred and might have had high risk of developing those outcomes regardless of their home loss status. However, more research is warranted to identify the potential mechanisms underlying temporal changes (or lack thereof) in disaster-health associations.

We note five limitations. First, we cannot preclude the possibility of unmeasured confounders; however, our study leveraged the natural experiment design and adjusted for a rich set of survivors' pre-disaster characteristics, including pre-disaster levels of outcomes, thereby minimizing the magnitude of reverse causation and residual bias by an unmeasured confounder.[43] Moreover, the E-value analysis suggested robustness of some observed associations (e.g., ones for PTSS and prosociality as outcomes) to residual confounding. Second, our exposure assessment was relatively crude. For instance, the effects of home loss may differ depending on value of the damaged properties, but we did not have such information. Third, a large number of the survivors in the study population passed away during the follow-up period: There were 434 deaths before the second wave and another 530 deaths before the fourth wave. Selective attrition as a result of these deaths and loss-to-follow-up may have induced selection bias and underestimated the true causal effect of home loss on the outcomes.[44]

Moreover, these deaths among the older adult population in Iwanuma might have affected survivors' social capital and social well-being. Fourth, this study examined population-average associations between home loss and the outcomes. Impacts of traumatic experiences might be heterogeneous and differ across social groups.[45] Thus, even for the outcomes that were not associated with home loss on average (e.g., cognitive disability), there may be some subpopulations in which home loss adversely affected health and well-being. Hence, future studies should investigate such effect heterogeneity. Last, the health and well-being impacts of disaster-related home loss may depend on the cohort and context. For example, Japan has a universal health care coverage system, and the health insurance covers most dental care services.[46] Having access to necessary dental care services would likely be protective against oral health problems and may explain the lack of evidence for the association between home loss and edentulism in this study. However, this finding may not be generalizable to other contexts with differential access to dental care services.

In conclusion, our study demonstrated, using a natural experimental design, that disaster-related home loss may have resulted in prolonged mental health problems, particularly increased PTSS, and decreased level of prosociality among older survivors of the 2011 Japan Earthquake and Tsunami even 9 y after the disaster. Evidence was mixed and more inconclusive for other domains of health and well-being. Although more research assessing the underlying mechanisms for these associations is needed, efforts to preserve and promote social capital in preparing post-disaster accommodations might be key to maintaining the health and well-being of older survivors in the long run.

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