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Increased risk of dementia in the aftermath of the 2011 Great East Japan Earthquake and Tsunami

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No previous study has been able to examine the association by taking account of risk factors for dementia before and after the disaster. We prospectively examined whether experiences of a disaster were associated with cognitive decline in the aftermath of the 2011 Great East Japan Earthquake and Tsunami. The baseline for our natural experiment was established in a survey of older community-dwelling adults who lived 80 km west of the epicenter 7 mo before the earthquake and tsunami. Approximately 2.5 y after the disaster, the follow-up survey gathered information about personal experiences of disaster as well as incidence of dementia from 3,594 survivors (82.1% follow-up rate). Our primary outcome was dementia diagnosis ascertained by in-home assessment during the follow-up period. Among our analytic sample (n = 3,566), 38.0% reported losing relatives or friends in the disaster, and 58.9% reported property damage. Fixed-effects regression indicated that major housing damage and home destroyed were associated with cognitive decline: regression coefficient for levels of dementia symptoms = 0.12, 95% confidence interval (CI): 0.01 to 0.23 and coefficient = 0.29, 95% CI: 0.17 to 0.40, respectively. The effect size of destroyed home is comparable to the impact of incident stroke (coefficient = 0.24, 95% CI: 0.11 to 0.36). The association between housing damage and cognitive decline remained statistically significant in the instrumental variable analysis. Housing damage appears to be an important risk factor for cognitive decline among older survivors in natural disasters.

dementia | disaster | natural experiment | Japan | instrumental variable analysis

Up to two-thirds of the affected populations in the 2011 Great East Japan Earthquake and Tsunami were older residents who were 60 y old or older (1). Recovery after major disaster poses a unique set of challenges for the elderly population, including disruption of medical care for preexisting conditions, preexisting functional limitations that impede recovery, and social isolation in the aftermath of housing loss and resettlement. A particular concern for older survivors is the potential risks of cognitive decline. In the 2011 earthquake and tsunami, an estimated 340,000 residents were displaced as a result of widespread destruction to residential properties. In turn, as a direct consequence of residential dislocation and resettlement in unfamiliar surroundings, many seniors experienced disorientation that could hasten cognitive decline (2). Psychological trauma, including posttraumatic stress disorder (PTSD) symptoms (3) and the onset of depression (4), may have additionally contributed to this risk.

Two years after the 2011 Great East Japan Earthquake and Tsunami, a cross-sectional study found that 36.0% of seniors who moved to temporary housing in Kesen-numa city were suffering from dementia symptoms (5). Another cross-sectional study of seniors affected by the disaster reported that 47.9% showed signs of mild cognitive impairment, and an additional 16.0% of respondents were diagnosed as having dementia (6). However, prospective studies of risk factors for cognitive decline in the aftermath of disaster remain extremely scarce. This scarcity is particularly true for risk factors that predate the disaster. Asking about predisaster conditions after the disaster is obviously subject to recall bias.

In the present study, we took advantage of a unique "natural experiment" in which information about health status was gathered 7 mo before the disaster. Our study area, Iwanuma city, located ~80 km west of the earthquake epicenter (Fig. 1), was one of the field sites of a cohort study of aging established in 2010. The Japan Gerontological Evaluation Study (JAGES) inquired about the health status, health behaviors, and social determinants of healthy aging in a nationwide sample of community-dwelling residents aged 65 y or older. Approximately 2.5 y after the disaster, we recontacted the 3,594 survivors (Fig. 2) and linked their responses to incident dementia symptoms ascertained by in-home assessment and medical examination under Japan's national Long-Term Care Insurance (LTCI) registry (Table S1). This unique design afforded us the opportunity to prospectively examine the association between disaster-related experiences and postdisaster cognitive decline.

Results

Table 1 presents the characteristics of respondents at baseline (before the disaster) and at follow-up 2.5 y later. Females made up 56.5% of respondents, and this proportion was very close to the actual local census of older residents in Iwanuma city in October 2010 (male 42.8%, female 57.2%) (7). The age distribution of our sample was close to the local census data, except for the group aged 85 y and over (respondents 6.2%, census data 13.2%) (7). A somewhat higher proportion of our respondents were married (71.4%) compared with the census data (64.7%) (8). The proportion of employed individuals in our data (17.8%) was also quite

Significance

Recovery after major disaster poses potential risks of dementia for the elderly population. However, no previous studies have examined exposure to natural disaster and changes in risk factors as predictors of deterioration in cognitive function. We prospectively examined whether housing damage and loss of relatives or friends were associated with cognitive decline in the aftermath of the 2011 Great East Japan Earthquake and Tsunami. In this study, which included 3,566 survivors who are 65 y old or older, the severity of housing damage was significantly associated with cognitive decline after controlling changes of covariates and risk factors during the follow-up period. The cognitive decline should be listed as a health risk of older survivors in the aftermath of natural disasters.

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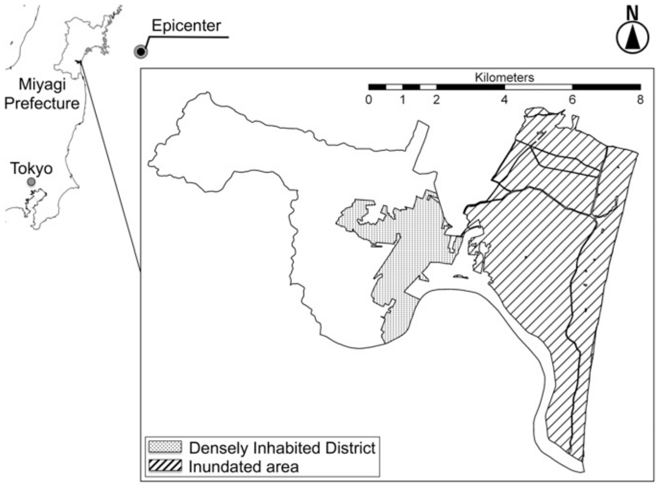

Fig. 1. Map of inundated area in Iwanuma city, Japan. Reproduced from ref. 38.

close to the census data (17.2%) (9). Our study population was less likely to be domiciled in households with four or more people compared with the census data (respondents 31.5%, census data 53.3%) (10). The proportion of individuals who were assessed to be cognitively independent was also higher in our analytic sample compared with the general older population in Iwanuma city (95.9% in our sample vs. 86.5% in the census data). These differences are likely a result of the fact that our sample was healthier than the general population and less likely to be living together with other caregivers (e.g., adult children).

In addition, we also compared the characteristics of our analytic sample versus nonrespondents to the follow-up survey (n = 786). The sex distribution was similar, although our analytic sample was somewhat older than the nonrespondents (Table S2). The proportion of married persons in our analytic sample (71.4%) was higher than among nonrespondents (64.9%). More respondents were likely to be used at the time of the follow-up survey (17.8%) compared with the nonrespondents (14.0%). The nonrespondents were also less classified as functionally independent (84.1%) compared with the analytic sample (95.9%). These comparisons support that our data almost represents whole older population in Iwanuma city (Table S2).

Among the respondents, 38.0% reported losing relatives or friends in the disaster, whereas 58.9% reported personal damage to their property (see further description of property damage in Table S3). The prevalence of respondents whose cognitive function was classified as nonindependent at the follow-up survey (11.5%) was three times higher than at baseline (4.1%). The prevalence of stroke (2.8%) and hypertension (54.0%) had also increased at the follow-up survey (to 6.5% and 57.2%, respectively). The prevalence of individuals who reported not interacting with their neighbors (not even greetings) nearly doubled over the 3-y follow-up (1.5 to 2.9%). The proportion of respondents with severe PTSD symptoms at follow-up was 11.4%.

As shown in Table 2, model 1 indicated that major housing damage and destroyed home was significantly associated with deterioration of dementia symptomatology: coefficient for levels of dementia symptoms (out of an eight-point scale) = 0.12, 95% confidence interval (CI): 0.01 to 0.23 for "major damage"; and coefficient = 0.29, 95% CI: 0.17 to 0.40, for "destroyed." In contrast, loss of relatives or friends did not show a significant association with cognitive impairment (coefficient = −0.03, 95% CI: −0.07 to 0.02).

Model 2 added the potential mediators. The onset of depression (coefficient = 0.11, 95% CI: 0.05 to 0.17) and lack of interactions with neighbors (coefficient = 0.09, 95% CI: 0.04 to 0.14) were significant. The addition of these mediators attenuated the relationship between levels of property damage and deterioration of dementia symptomatology (model 3). The most influential mediator was the new onset of depressive symptoms when we adjusted for one mediator at a time. The sensitivity analyses using the result of medical examination also showed same results (Table S4).

Finally, we combined instrumental variable analysis with our fixed-effects approach. The first stage F-statistics (329.48) suggested that distance from coast is a strong instrument (Fig. S1) (11). The residual of the first-stage regression in our instrumental variable analysis is significant in the second-stage regression (P = 0.02), suggesting that housing damage is endogenous (12). In addition, the inverse distance from the coast was not directly associated with cognitive decline after adjusting for all covariates (coefficient = 0.08, 95% CI: −0.01 to 0.17), suggesting that the exclusion restriction was met. We therefore used distance from the coast as a valid instrumental variable for housing damage and dementia. As shown in Table 3, our instrumental variable analysis also suggests that property damage is significantly associated with deterioration in dementia symptomatology. The sensitivity analyses for medical examination were also showed same results (Table S5).

Discussion

This study demonstrates that experiences of disaster are associated with the deterioration of dementia symptomatology, controlling changes of covariates and risk factors in a natural experimental setting. The associations remained after statistically controlling for observed and unobserved time-invariant personal traits as well as change of several risk factors for dementia before and after the disaster. The strength of the associations between property damage and dementia symptoms appears to be statistically and clinically important. For example, the impact on dementia symptoms following complete destruction of the housing

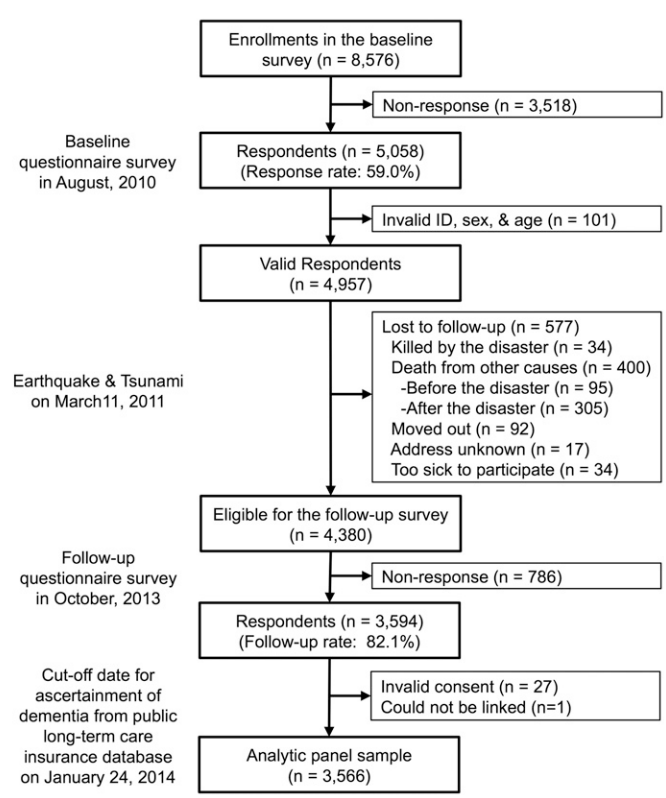

Fig. 2. Participants flow for analytic sample (n = 3,566).

Table 1. Characteristics of analytic sample in baseline and follow-up survey

Characteristic	Baseline survey in August 2010 *n*	Baseline survey in August 2010 %	Follow-up survey in October 2013 *n*	Follow-up survey in October 2013 %
Levels of dementia symptomatology				
Independent	3,421	95.9	3,156	88.5
I	77	2.2	181	5.1
IIa	6	0.2	51	1.4
IIb	52	1.5	116	3.3
IIIa	8	0.2	43	1.2
IIIb	2	0.1	15	0.4
IV	0	0.0	4	0.1
M	0	0.0	0	0.0
Total	3,566	100	3,566	100
House property damage*				
No damage			1,423	41.1
Affected			1,496	43.2
Minor			257	7.4
Major			131	3.8
Destroyed			158	4.6
Total			3,465	100
Loss of relatives and/or friends*				
No			2,166	62.0
Yes			1,329	38.0
Total			3,495	100
Age				
65–74 y	2,127	59.7	1,498	42.0
75–84 y	1,219	34.2	1,580	44.3
85+ y	220	6.2	488	13.7
Total	3,566	100	3,566	100
Equivalized income				
Under 2.0 million JPY	1,422	48.9	1,586	53.1
2.0 million JPY and over	1,489	51.2	1,400	46.9
Total	2,911	100	2,986	100
Stroke				
No	2,664	97.2	2,845	93.6
Yes	77	2.8	196	6.5
Total	2,741	100	3,041	100
Hypertension				
No	1,262	46.0	1,302	42.8
Yes	1,479	54.0	1,739	57.2
Total	2,741	100	3,041	100
Diabetes				
No	2,285	83.4	2,551	83.9
Yes	456	16.6	490	16.1
Total	2,741	100	3,041	100
Dyslipidemia				
No	2,371	86.5	2,623	86.3
Yes	370	13.5	418	13.8
Total	2,741	100	3,041	100
Current drinking				
No	2,208	63.4	2,421	68.4
Yes	1,277	36.6	1,121	31.7
Total	3,485	100	3,542	100
Current smoking				
No	2,903	88.8	3,265	92.2
Yes	366	11.2	278	7.9
Total	3,269	100	3,543	100
Walking time				
90 min and over	435	12.8	470	13.4
60–89 min	493	14.5	534	15.2
30–59 min	1,183	34.9	1,227	34.9
Under 30 min	1,284	37.8	1,281	36.5
Total	3,395	100	3,512	100

Table 1. Cont.

Characteristic	Baseline survey in August 2010 *n*	Baseline survey in August 2010 %	Follow-up survey in October 2013 *n*	Follow-up survey in October 2013 %
Disruption of access to internal medicine and/or psychiatry*				
No			3,263	94.9
Yes			175	5.1
Total			3,438	100
PTSD*				
Slight (0–3 points)			2,481	74.1
Moderate (4–5 points)			486	14.5
Severe (6–9 points)			380	11.4
Total			3,347	100
Depression symptom (GDS-15)				
Four points and under	2,090	68.0	2,072	66.9
Five points and over	984	32.0	1,026	33.1
Total	3,074	100	3,098	100
Informal socializing with friends				
Four or more a week	422	12.4	507	14.4
Two or three times a week	846	24.8	770	21.9
Once a week	609	17.8	473	13.5
One to three times a month	721	21.1	789	22.4
A few times a year	568	16.6	649	18.5
Rarely	248	7.3	329	9.4
Total	3,414	100	3,517	100
Interactions with neighbors				
Mutual consultation, lending and borrowing daily commodities, cooperation in daily life	827	24.0	714	20.2
Standing and chatting frequently	1,938	56.2	1,977	56.0
No more than exchanging greetings	632	18.3	734	20.8
None, not even greetings	51	1.5	103	2.9
Total	3,448	100	3,528	100
Sex (time-invariant variable)†				
Male	1,552	43.5		
Female	2,014	56.5		
Total	3,566	100		
Educational attainment (time-invariant variable)†				
9 y and under	1,229	35.9		
10 y and over	2,199	64.1		
Total	3,428	100		

*Empty cells at baseline because was before the disaster.
†Empty cells at follow-up because of time-invariant variables.

(coefficient = 0.29, 95% CI: 0.17 to 0.40 in model 1 of Table 2) is comparable to the impact of incident stroke (coefficient = 0.24, 95% CI: 0.11 to 0.36). Additionally, the loss of housing is close to the 3-y decline in cognitive function in our sample (coefficient = 0.32, 95% CI: 0.28 to 0.37). We confirmed that the association between housing damage and cognitive decline was significant in sensitivity analysis that the outcome was the result of medical examination. In addition, the results of the instrumental variable analysis with the fixed-effect model also showed the significant association. Therefore, the effect of housing damage on cognitive decline is a robust finding.

Previous studies have hinted that experiences of the 2011 Great East Japan Earthquake and Tsunami are linked with heightened risk of cognitive decline (5, 6, 13–15). In the United States, Cherry et al. showed that short-term and working-memory performance was adversely affected in the aftermath of Hurricanes Katrina and Rita (16). At an additional follow-up examination 6–14 mo after the disaster, the respondent's working-memory performance had recovered from the prior survey (17). However, Cherry et al. (16, 17) did not specifically examine the effects of housing damage or other risk factors for cognitive decline predating the disaster.

There are plausible mechanisms linking property damage to cognitive function of older people, including: (*i*) new onset of depression and (*ii*) disruption of social contacts. Our mediation analysis (model 3) indicated that depression and loss of interactions with neighbors partially mediated the relation between property damage and cognitive decline.

In contrast to experiences of property damage, the loss of relatives or friends was not significantly associated with cognitive decline. We also checked the endogeneity of loss of relatives or friends by using residence in the tsunami-inundated area as our instrument. The proportion of respondents who lost relatives or friends in the inundated area (60.9%) was approximately twice as high as those who lived in noninundated areas (33.9%), *F*-statistics = 19.97. However, the instrumental variable analysis indicated that loss of relatives/friends was not significantly associated with cognitive decline (coefficient = 0.07; 95% CI: –0.15 to 0.29). However, we did not inquire on the baseline survey about the frequency of social interactions between the survivors and the relatives/friends who

Table 2. Disaster damage and deterioration of dementia symptomatology assessed by in-home assessment

	Model 1		Model 2		Model 3	
Damage and assessment	Coef. (95% CI)	*P* value	Coef. (95% CI)	*P* value	Coef. (95% CI)	*P* value
Housing damage (Ref.: no damage = 1)						
Partial = 2	0.05 (−0.01 to 0.10)	0.05			0.04 (−0.01 to 0.09)	0.09
Minor = 3	0.07 (−0.02 to 0.16)	0.12			0.05 (−0.04 to 0.14)	0.24
Major = 4	0.12 (0.01 to 0.23)	0.03			0.10 (−0.01 to 0.21)	0.09
Destroyed = 5	0.29 (0.17 to 0.40)	<0.001			0.24 (0.12 to 0.36)	<0.001
Loss of relatives and/or friends						
Yes = 1, No = 0	−0.03 (−0.07 to 0.02)	0.26			−0.04 (−0.08 to 0.01)	0.15
Age						
Continuous	0.32 (0.28 to 0.37)	<0.001	0.32 (0.28 to 0.36)	<0.001	0.32 (0.27 to 0.36)	<0.001
Equivalized income (Ref.: <2 million = 0)						
≥2 million = 1	0.01 (−0.04 to 0.05)	0.84	−0.01 (−0.05 to 0.05)	0.94	−0.01 (−0.05 to 0.05)	0.99
Stroke						
Yes = 1, No = 0	0.24 (0.11 to 0.36)	<0.001	0.23 (0.11 to 0.35)	<0.001	0.23 (0.10 to 0.35)	<0.001
Hypertension						
Yes = 1, No = 0	−0.03 (−0.08 to 0.03)	0.38	−0.03 (−0.08 to 0.03)	0.40	−0.03 (−0.08 to 0.03)	0.39
Diabetes						
Yes = 1, No = 0	0.02 (−0.04 to 0.08)	0.54	0.02 (−0.04 to 0.07)	0.54	0.02 (−0.04 to 0.08)	0.52
Dyslipidemia						
Yes = 1, No = 0	0.02 (−0.05 to 0.10)	0.54	0.02 (−0.05 to 0.10)	0.55	0.02 (−0.05 to 0.10)	0.54
Drinking						
Yes = 1, No = 0	0.04 (−0.03 to 0.12)	0.27	0.04 (−0.03 to 0.12)	0.25	0.05 (−0.03 to 0.12)	0.24
Smoking						
Yes = 1, No = 0	−0.10 (−0.22 to 0.02)	0.11	−0.07 (−0.19 to 0.05)	0.26	−0.08 (−0.19 to 0.04)	0.21
Decreased walking time						
1: ≥90 m–4: <30 m	0.05 (0.02 to 0.07)	<0.001	0.04 (0.02 to 0.07)	<0.001	0.04 (0.02 to 0.07)	<0.001
The length of time between predisaster and postdisaster assessment						
Continuous	−0.25 (−0.29 to −0.21)	<0.001	−0.24 (−0.28 to −0.21)	<0.001	−0.25 (−0.28 to −0.21)	<0.001
Disruption of access to internal medicine and/or psychiatry						
Yes = 1, No = 0			−0.09 (−0.63 to 0.45)	0.75	−0.13 (−0.66 to 0.41)	0.65
PTSD (Ref.: slight = 1)						
Moderate = 2			0.06 (−0.01 to 0.13)	0.08	0.05 (−0.02 to 0.11)	0.16
Severe = 3			0.07 (−0.01 to 0.14)	0.08	0.05 (−0.03 to 0.12)	0.23
Depression						
≥5 *P* = 1, ≤4 *P* = 0			0.11 (0.05 to 0.17)	<0.001	0.10 (0.05 to 0.16)	<0.001
Lacked informal socializing with friends						
1: Most–6: Rare			0.04 (−0.01 to 0.10)	0.13	0.05 (−0.01 to 0.10)	0.11
Lacked interactions with neighbors						
1: Most–4: None			0.09 (0.04 to 0.14)	<0.001	0.08 (0.03 to 0.13)	0.002

Coef., coefficient; Ref., reference.

were lost. Some of them may have interacted with the survivors on a daily basis before the disaster, in which case their loss could have contributed to risk of cognitive decline.

A major strength of this study is the availability of information predating the disaster about levels of dementia symptomatology, as well as other health conditions. Our design was therefore able to effectively address the problem of recall bias in most studies conducted in postdisaster settings. A second strength is the record linkage to medically verified dementia symptomatology obtained through home visits.

Despite our attempts to control for major confounding factors, we cannot exclude the possibility that housing damage was endogenous; that is, people at risk for cognitive decline were also more likely to be living in vulnerable housing. For example, lower educational attainment and equivalent income were both correlated with severity of housing damage (Tables S6 and S7). Even though we controlled for education and income, there may be other residual confounding factors. Thus, it was important to demonstrate that the same association between property damage and dementia symptomatology was observed in our instrumental variable analysis.

Selection bias might have arisen because of the 59% response rate to the baseline survey. However, this response rate is quite comparable to similar surveys involving community-dwelling residents (18). In addition, we confirmed that the demographic profile of our participants is quite similar to the rest of Iwanuma residents aged 65 y or older (Table S2). Furthermore, the response rate of our follow-up survey among survivors was quite high (82.1%). Because of the compulsory residential registration system in Japan, only 17 residents from the baseline sample could not be tracked (Fig. 2). The estimated effects from the instrumental variable model were larger than the fixed-effects model. This difference may be because of the correction of measurement error associated with the assessment of housing damage that was obtained by self-report (19). At the same time, we also note that the extent of housing damage was not just based on subjective perception, but based on two independent assessors dispatched to each damaged house. In addition, our findings likely underestimated the impact of this large-scale disaster on the dementia risk of survivors. That is, even among survivors whose homes were not inundated or destroyed, they may still be at increased risk of cognitive decline because of other trauma experiences (e.g., depression).

Table 3. Result of the instrumental variable analysis with the fixed-effect model using in-home assessment

			Instrumental variable analysis + fixed-effect model*			
	Fixed-effect model		Second stage		First stage†	
Variable	Coef. (95% CI)	*P* value	Coef. (95% CI)	*P* value	Coef. (95% CI)	*P* value
Housing damage (continuous)						
1: No–5: Destroy	0.05 (0.02 to 0.07)	<0.001	0.08 (0.05 to 0.12)	<0.001		
Inversed distance from coast						
1/km					1.36 (1.29 to 1.42)	< 0.001
Loss of relatives and/or friends						
Yes = 1, No = 0	−0.03 (−0.08 to 0.01)	0.17	−0.05 (−0.10 to 0.01)	0.06	0.20 (0.14 to 0.26)	<0.001
Age						
Continuous	0.32 (0.27 to 0.36)	<0.001	0.31 (0.27 to 0.35)	<0.001	0.05 (−0.01 to 0.10)	0.10
Equivalized income (Ref.: <2 million = 0)						
≥2 million = 1	−0.01 (−0.05 to 0.05)	0.99	0.01 (−0.05 to 0.05)	0.99	0.01 (−0.06 to 0.06)	0.99
Stroke						
Yes = 1, No = 0	0.22 (0.10 to 0.35)	<0.001	0.22 (0.09 to 0.34)	0.001	0.09 (−0.06 to 0.24)	0.24
Hypertension						
Yes = 1, No = 0	−0.03 (−0.08 to 0.03)	0.39	−0.03 (−0.08 to 0.03)	0.38	0.01 (−0.07 to 0.08)	0.93
Diabetes						
Yes = 1, No = 0	0.02 (−0.04 to 0.08)	0.50	0.02 (−0.04 to 0.08)	0.47	−0.04 (−0.11 to 0.03)	0.30
Dyslipidemia						
Yes = 1, No = 0	0.02 (−0.05 to 0.10)	0.54	0.02 (−0.05 to 0.10)	0.54	0.01 (−0.09 to 0.10)	0.88
Drinking						
Yes = 1, No = 0	0.05 (−0.03 to 0.12)	0.23	0.05 (−0.03 to 0.12)	0.23	−0.06 (−0.15 to 0.04)	0.24
Smoking						
Yes = 1, No = 0	−0.08 (−0.19 to 0.04)	0.21	−0.08 (−0.20 to 0.04)	0.18	0.08 (−0.06 to 0.23)	0.27
Decreased walking time						
1: ≥90 m–4: <30 m	0.04 (0.02 to 0.07)	<0.001	0.04 (0.02 to 0.06)	<0.001	0.03 (0.01 to 0.06)	0.02
The length of time between predisaster and postdisaster assessment						
Continuous	−0.25 (−0.28 to −0.21)	<0.001	−0.25 (−0.29 to −0.21)	<0.001	0.07 (0.02 to 0.11)	0.004
Disruption of access to internal medicine and/or psychiatry						
Yes = 1, No = 0	−0.13 (−0.67 to 0.41)	0.64	−0.16 (−0.7 to 0.38)	0.57	0.10 (−0.57 to 0.76)	0.78
PTSD (Ref.: slight = 1)						
Moderate = 2	0.05 (−0.02 to 0.11)	0.17	0.04 (−0.03 to 0.10)	0.31	0.21 (0.12 to 0.30)	<0.001
Severe = 3	0.05 (−0.03 to 0.12)	0.24	0.03 (−0.05 to 0.10)	0.50	0.31 (0.22 to 0.40)	<0.001
Depression						
≥5 *P* = 1, ≤4 *P* = 0	0.11 (0.05 to 0.16)	<0.001	0.10 (0.05 to 0.16)	<0.001	0.02 (−0.05 to 0.09)	0.56
Lacked informal socializing with friends						
1: Most–6: Rare	0.04 (−0.01 to 0.10)	0.13	0.04 (−0.01 to 0.10)	0.13	0.04 (−0.03 to 0.11)	0.28
Lacked interactions with neighbors						
1: Most–4: None	0.08 (0.03 to 0.13)	0.001	0.08 (0.02 to 0.13)	0.004	0.08 (0.02 to 0.15)	0.008

Ref., reference.
*The endogeneity test of housing damage is significant ($P = 0.02$).
†F-statistics of the first stage is 329.48.

We demonstrated that experiences of housing damage are associated with deterioration of dementia symptomatology. Cognitive decline should be added to the list of health risks faced by older survivors of disaster.

Methods

Study Participants. JAGES is a nationwide cohort study established in 2010 to examine prospectively the predictors of healthy aging. A total of 169,215 community-dwelling people aged 65 y or older in 31 municipalities were mailed a baseline questionnaire, and 112,123 individuals responded to the invitation (response rate 66.3%) (20).

One of the field sites of the JAGES cohort is based in the city of Iwanuma (total population 44,187 in 2010) (7) in Miyagi Prefecture. We mailed questionnaires to all residents aged 65 y or older in August 2010 (n = 8,576), using the official residential register. The survey inquired about personal characteristics as well as their health status. The response rate was 59.0% (n = 5,058), which is comparable to other surveys of community-dwelling residents.

The earthquake and tsunami occurred on March 11, 2011, 7 mo after the baseline survey was completed. Iwanuma city is a coastal municipality located ∼80 km west of the earthquake epicenter, so that it was in the direct line of the tsunami that killed 180 residents, damaged 5,542 homes, and inundated 48% of the land area (Fig. 1) (21).

Approximately 2.5 y after the disaster (starting on October 2013), we conducted a follow-up survey of all survivors. The survey gathered information about personal experiences of disaster as well as updating their health status. Informed consent was obtained at the time of survey collection. The respondents were then linked to the national LTCI registry, which includes information about dementia symptomatology based on in-home assessment by trained investigators (e.g., public health nurse).

The detailed flow-chart of the analytic sample is presented in Fig. 2. Of the 4,380 eligible participants from the baseline survey, we managed to recontact 3,594 individuals (follow-up rate: 82.1%). Our analytic sample is 3,566 because of incompletely signed informed consent forms and lack of linkage to the national LTCI database.

The survey protocol was reviewed and approved by the human subjects committee of the Harvard T. H. Chan School of Public Health, as well as the human subjects committees of Tohoku University, Nihon Fukushi University, and Chiba University. In principle, outside researchers can access the data of JAGES upon request, as per NIH data access policies. We would require the applicant to submit an analysis proposal that would be reviewed by an internal committee of JAGES investigators to avoid duplication. We are not able to deposit our data for public sharing because the data are from an ongoing cohort study of community-dwelling individuals (a one in six sample of a midsize town), and we need to protect their confidentiality.

Outcome Variable. Our primary outcome is dementia symptomatology assessed by a standardized in-home assessment. The Japanese government established a national LTCI scheme in 2000 (22). Under the LTCI, a certification committee in each municipality dispatches a trained investigator to an applicants' home to evaluate their eligibility for elderly care (e.g., home helpings).

During the home visit, the individual is assessed with regard to their activities of daily living and instrumental activities of daily living status, cognitive function (e.g., short-term memory, orientation, and communication), as well as mental and behavioral disorders (e.g., delusions of persecution, confabulation, and soliloquy) using a standardized protocol. Following the assessment, the applicants are classified into one of eight levels according to the severity of their cognitive disability (Table S1). The index of dementia symptomatology is strongly correlated with the Mini Mental State Examination (Spearman's rank correlation $\rho = -0.73$, $P < 0.001$) (23), and the level I of dementia symptomatology has been demonstrated to correspond with a 0.5 point rating on the Clinical Dementia Rating (specificity and sensitivity 0.88, respectively) (24). The initial certification is valid for 6 mo, after which periodic reassessments are generally conducted every 12 mo (25). The certified persons can require the reassessment before the expiration date, when their health status radically changes (22).

The certification committee also asks physicians to assess the cognitive disability level of applicants to refer an expert's opinion when they decide the care level of the applicants (26). The medical examination is independent of the investigator's in-home assessment, but we confirmed a high correlation between changes of dementia level of both assessment (Pearson's correlation $\gamma = 0.80$, $P < 0.001$). We used the medical examination in our sensitivity analyses.

We linked JAGES cohort participants to the LTCI register in Iwanuma city for the follow-up period from April 1, 2010 to January 24, 2014. These data includes the results of the initial assessment as well as subsequent reassessments for each individual.

Explanatory Variables. Our primary exposure variable of interest is personal experiences of trauma in the disaster: housing damage as well as loss of relatives or friends.

The question about housing damage is based on objectively established criteria for the purposes of compensation of victims. Two or more technical officers surveyed the properties and classified the extent of damage into five levels: (*i*) "no damage," (*ii*) "partial damage," (*iii*) "minor," (*iv*) "major," and (*v*) "destroyed" (Table S3).

Covariates and Mediators. We selected as potential time-varying confounding variables: age, equivalized income (27), medical treatment for stroke, hypertension, diabetes (28), dyslipidemia (29), current smoking (30), current alcohol drinking (31), and daily walking time (32). Other time invariant characteristics, such as sex and educational attainment, were omitted from our fixed-effects regressions (33). We also controlled for length of time (in years) between the predisaster and postdisaster assessments for each subject (mean 3.69, SD 0.38).

We additionally examined a set of variables as potential mediators of the relation between property damage/loss and dementia symptomatology. These variables were included: disruption to access to internal medicine and psychiatric services, incident PTSD and depression symptoms (measured by the Geriatric Depression Scale-15, GDS-15) (4), and declines in informal social interactions with friends and neighbors. The informal socializing variable was measured in terms of the reported frequency of meeting with friends, ranging from "four or more times a week" to "rarely." Interactions with neighbors was asked in terms of how close the respondents felt to their neighbors, ranging from "mutual consultation, lending and borrowing of daily commodities, cooperation in daily life" to "none, not even greeting their neighbors." PTSD symptoms were assessed using the Screening Questionnaire for Disaster-Related Mental Health (34), which has been previously validated in an older Japanese population. PTSD symptoms were categorized into slightly affected (0–3 points), moderately affected (4–5 points), and severely affected (6–9 points) (34).

Age was grouped into "65 to 74 y," "74 to 84 y," and "85 y and over." Household income was equalized by dividing the gross income by the square root of the number of household members and categorized into "Under 2.0 million JPY" (Japanese yen) versus "2.0 million JPY and over." Depressive symptoms were categorized into lower risk (four points and under) versus higher risk (five points and over) (35).

Statistical Analysis. In the present study, we used a fixed-effects regression approach to examine the associations between property damage and changes in dementia symptomatology over time. In the case of two-wave panel data, the model is equivalent to a first-difference model (36). That is, the model estimates within-individual changes in the dependent variable ($\triangle$Y: change in level of dementia symptomatology) regressed on changes in the independent variable ($\triangle$X: experiences of disaster damage), which effectively differences out the confounding influences of all observed and unobserved time-invariant factors. The causal interpretation of this model can still be questioned if changes in the outcome influenced changes in the exposure. However, in our natural experiment, we argue that the exposure itself (i.e., experiences of the disaster) was an exogenous shock, and that the resulting coefficients can be interpreted as causal.

Property damage in a disaster is a potentially endogenous variable; that is, residents who are more susceptible to cognitive decline may be also more likely to be living in homes that are vulnerable to damage. We need to reduce the estimation bias caused by the endogeneity of housing damage after adjusting observed covariates and risk factors. Therefore, as a robustness check to account for residual confounding, we additionally conducted an instrumental variable analysis, using the inverse of distance from the coastline to each resident's address at baseline as an instrument for housing damage. A valid instrument requires that it be associated with the treatment, but not directly affect the outcome (37). We calculated the distance for each residence using geographic information systems. The extent of housing damage was strongly correlated with distance from the coast (Fig. S1).

To address potential bias resulting from missing data, we used multiple imputation by Markov chain–Monte Carlo method assuming missingness at random for explanatory variables and covariates. We created 50 imputed datasets and combined each result of analysis using the STATA command "mi estimate."

All analyses were performed using STATA v14.0 (STATA).

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1. Cabinet Office, Government of Japan (2013) *Kōrei Syakai Hakusyo. Annual Report on the Aging Society: 2013.* (Insatsu tsūhan, Tokyo). Japanese.
2. Heller T (1982) The effects of involuntary residential relocation: a review. *Am J Community Psychol* 10(4):471–492.
3. Schuitevoerder S, et al. (2013) A meta-analysis of cognitive functioning in older adults with PTSD. *J Anxiety Disord* 27(6):550–558.
4. Mourao RJ, Mansur G, Malloy-Diniz LF, Castro Costa E, Diniz BS (2016) Depressive symptoms increase the risk of progression to dementia in subjects with mild cognitive impairment: Systematic review and meta-analysis. *Int J Geriatr Psychiatry* 31(8):905–911.
5. Ishiki A, et al. (2015) Cognitive examination in older adults living in temporary apartments after the Great East Japan Earthquake. *Geriatr Gerontol Int* 15(2): 232–233.
6. Akanuma K, et al.; Tome Project Members (January 12, 2016) Disturbed social recognition and impaired risk judgement in older residents with mild cognitive impairment after the Great East Japan Earthquake of 2011: The Tome Project. *Psychogeriatrics*, 10.1111/psyg.12175.
7. Iwanuma City (2010) Nenrei Kakusai Danjyo betsu Jinkou no Suii. [Change of Population by Age Group and Sex.] Available at www.city.iwanuma.miyagi.jp/kakuka/010300/010306/documents/4nenreikakusaijinkousuii.pdf. Accessed June 29, 2015. Japanese.
8. Iwanuma City (2010) Haigū Kankei, Nenrei, Danjyo betsu ijyō Jinkou. [Population 15 Years of Age and Over, by Marital Status (4 Groups), Age (Five-Year Groups), Sex and Average Age.]. Available at www.city.iwanuma.miyagi.jp/kakuka/010300/010306/documents/7haiguukankeidanjobetsujinkou.pdf. Accessed July 28, 2015. Japanese.
9. Iwanuma City (2010) Jyōjyū chi mata ha Jyūgyō chi Tsūgaku chi ni yoru Nenrei. [Population and Employed Persons 15 Years of Age and Over, based on Place of Usual Residence and Place of Working or Schooling, by Age (Five-Year Groups) and Sex.] Available at www.city.iwanuma.miyagi.jp/kakuka/010300/010306/documents/23joujuuchimatahajuugyouchinojinnkou.pdf. Accessed July 28, 2015. Japanese.
10. Iwanuma City (2010) Shinzoku betsu 65 sai ijyō shinzoku no iru ippan setai sū, ippan setai jin'in oyobi 65 sai ijyō shinzoku jin'in. [Private Households, by Size of Household (7 Groups), Presence of Household Members 65 Years of Age and Over.] Available at www.city.iwanuma.miyagi.jp/kakuka/010300/010306/documents/15shinzokujininbetsu65saiijoushinzokunoirusetaisuu.pdf. Accessed July 2, 2016. Japanese.

11. Staiger DO (1997) Instrumental variables regression with weak instruments. *Econometrica* 65(3):557–586.
12. Wooldridge JM (2002) Additional single-equation topics. *Econometric Analysis of Cross Section and Panel Data* (MIT Press, Cambridge, MA), pp 115–139.
13. Furukawa K, Ootsuki M, Kodama M, Arai H (2012) Exacerbation of dementia after the earthquake and tsunami in Japan. *J Neurol* 259(6):1243.
14. Furukawa K, et al. (2013) Aggravation of Alzheimer's disease symptoms after the earthquake in Japan: A comparative analysis of subcategories. *Geriatr Gerontol Int* 13(4): 1081–1082.
15. Meguro K, Akanuma K, Toraiwa K, Okubo M, Onodera K (2014) Behavioral improvement of dementia residents in a group home with an increased number of residents after the Great East Japan Earthquake 2011. *Int Psychogeriatr* 26(5):871–872.
16. Cherry KE, et al. (2010) Cognitive and psychosocial consequences of Hurricanes Katrina and Rita among middle-aged, older, and oldest-old adults in the Louisiana Healthy Aging Study (LHAS). *J Appl Soc Psychol* 40(10):2463–2487.
17. Cherry KE, et al. (2011) Longitudinal assessment of cognitive and psychosocial functioning after Hurricanes Katrina and Rita: Exploring disaster impact on middle-aged, older, and oldest-old adults. *J Appl Biobehav Res* 16(3-4):187–211.
18. Santos-Eggimann B, Cuénoud P, Spagnoli J, Junod J (2009) Prevalence of frailty in middle-aged and older community-dwelling Europeans living in 10 countries. *J Gerontol A Biol Sci Med Sci* 64(6):675–681.
19. Ailawadi KL, Farris PW, Parry ME (1999) Market share and ROI: Observing the effect of unobserved variables. *Int J Res Mark* 16(1):17–33.
20. Saito M, et al. (2014) Relative deprivation, poverty, and subjective health: JAGES cross-sectional study. *PLoS One* 9(10):e111169.
21. Miyagi Prefecture (2016) Higashi Nihon Daishinsai ni okeru Higai tou Jyōkyō. [Current situations of damage and evacuation]. Available at www.pref.miyagi.jp/uploaded/attachment/347652.pdf. Accessed March 27, 2016. Japanese.
22. Tamiya N, et al. (2011) Population ageing and wellbeing: Lessons from Japan's long-term care insurance policy. *Lancet* 378(9797):1183–1192.
23. Hisano S (2009) Kaitei Hasegawa shiki Kan'i Chinou Hyouka Scale (HDS-R), Mini-Mental State Examination (MMSE) to Syōgai Rōjin no Nichijyō Seikatsu Jiritsu do no Kanren ni tsuite. [The relationship between Revised Hasegawa Dementia Scale (HDS-R), Mini-Mental State Examination (MMSE) and Bed-fast Scale, Dementia Scale]. *Japanese Journal of Geriatric Psychiatry* 20(8):883–891. Japanese.
24. Meguro K, et al. (2012) Prevalence of dementia and dementing diseases in the old-old population in Japan: The Kurihara Project. Implications for long-term care insurance data. *Psychogeriatrics* 12(4):226–234.
25. Ministry of Health, Labour and Welfare (2015) Yōkaigo Nintei ni kakawaru Hōrei. [A Law Concerning Certification of Needed Long-Term Care]. Available at www.mhlw.go.jp/topics/kaigo/nintei/gaiyo4.html. Accessed November 9, 2015. Japanese.
26. Olivares-Tirado P, Tamiya N (2014) Development of the Long-Term Care Insurance System in Japan. *Trends and Factors in Japan's Long-Term Care Insurance System, Springer Briefs in Aging* (Springer, Dordrecht, The Netherlands), pp 15–42.
27. Cahill S, Pierce M, Werner P, Darley A, Bobersky A (2015) A systematic review of the public's knowledge and understanding of Alzheimer's disease and dementia. *Alzheimer Dis Assoc Disord* 29(3):255–275.
28. Tang EYH, et al. (2015) Current developments in dementia risk prediction modelling: An updated systematic review. *PLoS One* 10(9):e0136181.
29. Reitz C, et al. (2010) A summary risk score for the prediction of Alzheimer disease in elderly persons. *Arch Neurol* 67(7):835–841.
30. Ohara T, et al. (2015) Midlife and late-life smoking and risk of dementia in the community: The Hisayama Study. *J Am Geriatr Soc* 63(11):2332–2339.
31. Zhou H, et al. (2003) Study of the relationship between cigarette smoking, alcohol drinking and cognitive impairment among elderly people in China. *Age Ageing* 32(2): 205–210.
32. Murai T, et al. (2016) Prevention of cognitive and physical decline by enjoyable walking-habituation program based on brain-activating rehabilitation. *Geriatr Gerontol Int* 16(6):701–708.
33. Chang H-H (2013) Functional food consumption and depression among the elderly—What can we learn from a longitudinal survey? *Econ Model* 33:187–193.
34. Fujii S, Kato H, Maeda K (2008) A simple interview-format screening measure for disaster mental health: an instrument newly developed after the 1995 Great Hanshin Earthquake in Japan—The Screening Questionnaire for Disaster Mental Health (SQD). *Kobe J Med Sci* 53(6):375–385.
35. Weintraub D, Oehlberg KA, Katz IR, Stern MB (2006) Test characteristics of the 15-item geriatric depression scale and Hamilton depression rating scale in Parkinson disease. *Am J Geriatr Psychiatry* 14(2):169–175.
36. Boyce CJ, Wood AM, Powdthavee N (2013) Is personality fixed? Personality changes as much as "variable" economic factors and more strongly predicts changes to life satisfaction. *Soc Indic Res* 111(1):287–305.
37. Khandker SR, Koolwal GB, Samad H (2010) Instrumental variable estimation. *Handbook on Impact Evaluation: Quantitative Methods and Practices* (World Bank, Washington, DC), pp 87–100.
38. Hikichi H, Aida J, Tsuboya T, Kondo K, Kawachi I (2016) Can community social cohesion prevent posttraumatic stress disorder in the aftermath of a disaster? A natural experiment from the 2011 Tohoku Earthquake and Tsunami. *Am J Epidemiol* 183(10): 902–910.