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Original Article

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Bidirectional associations between post-traumatic stress symptoms and sleep quality among older survivors of the 2011 Great East Japan Earthquake and Tsunami

Aki Yazawa[1,2,*], Koichiro Shiba[3], Sakurako Shiba Okuzono[1], Hiroyuki Hikichi[4] and Ichiro Kawachi[1]

[1]Department of Social and Behavioral Sciences, Harvard T.H. Chan School of Public Health, Boston, MA, USA,
[2]Department of Epidemiology and Prevention, Center for Clinical Sciences, National Center for Global Health and Medicine, Tokyo, Japan,
[3]Department of Epidemiology, Boston University School of Public Health, Boston, MA, USA and
[4]Division of Public Health, Kitasato University School of Medicine, Kanagawa, Japan

*Corresponding author. Aki Yazawa, Department of Social and Behavioral Sciences, Harvard T. H. Chan School of Public Health, 677 Huntington Ave. Boston, MA 02115, USA. Email: aki.yazawa@gmail.com.

Abstract

Study Objectives: We sought to examine the bidirectional associations between post-traumatic stress symptoms (PTSS) and sleep quality in a sample of older disaster survivors.

Methods: We used 4 waves (2010, 2013, 2016, and 2020) of the Iwanuma Study, which included pre-disaster information and 9 years of follow-up data among older survivors of the 2011 Great East Japan Earthquake and Tsunami. Poisson regression analysis was used to examine the bidirectional associations between sleep problems and PTSS.

Results: Individuals reporting sleep problems before the disaster were more likely to develop PTSS after exposure to disaster trauma, while there was no effect modification, i.e. prevalence ratio for sleep problems did not differ by the magnitude of disaster damages. Individuals reporting sleep problems after the disaster were less likely to recover from PTSS, and more likely to develop the delayed onset of PTSS 5 years after the disaster. While individuals who recovered from PTSS 9 years after the disaster were still at slightly higher risk of having sleep problems compared to those who never had PTSS, none of the sleeping problems were found to be significantly prevalent after the Bonferroni correction.

Conclusions: Pre-disaster sleep problems predicted PTSS onset independently of experiences of disaster trauma. The association between PTSS and sleep problems was bidirectional. Intervening to mitigate lingering sleep problems may benefit the recovery of disaster survivors from post-traumatic symptoms.

Key words: Post-Traumatic Stress Disorder (PTSD); Gerontology; Epidemiology

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Graphical Abstract

Bidirectional associations between posttraumatic stress symptoms and sleep quality among older survivors of the 2011 Great East Japan Earthquake and Tsunami

Study objectives

To understand whether
(1) those who already reported sleep problems before the disaster were more likely to develop posttraumatic stress symptoms (PTSS)
(2) sleep problems after the disaster prevent recovery from PTSS
(3) increase the risk of later onset of PTSS
(4) those who recovered from PTSS also recovered from sleep problems

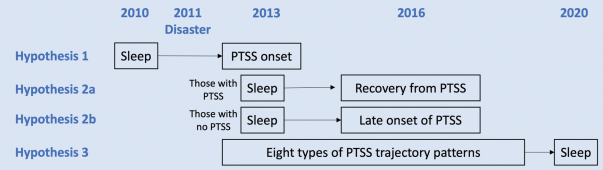
Methods

Data
- Pre- (2010) and post-disaster (2013, 2020) data of older survivors of the 2011 Great East Japan Earthquake and Tsunami in Iwanuma City, Miyagi (n=1,788 for 2020 wave)

Main variables
- Disaster damages
- PTSS: Screening Questionnaire for Disaster Mental Health (range: 0 – 9)
- Sleep quality
  - Five indicators (short sleep, sleep insufficiency, poor sleep quality, insomnia symptoms, and sleep medication use) from the Pittsburgh Sleep Quality Index in 2010 and 2013
  - Athens Insomnia Scale in 2020

Statistical analysis
- A Poisson regression analysis with a robust variance estimator

Results



H1. Pre-disaster sleep insufficiency was associated with onset PTSS even in the absence of disaster damages.
H2a. Those with poor sleep quality were less likely to recover from PTSS.
H2b. Short sleep was associated with increased risk of delayed onset of PTSS.
H3. Those who had PTSS throughout the post-disaster period were more likely to suffer from sleep problems than those who never had PTSS.

Findings

We found evidence for both directions of association
- Those who slept well before the disaster were less likely to develop PTSS.
- Those slept well after the disaster were more likely to recover from PTSS.

Conclusion
- Given the high prevalence of long-term PTSS, and the fact that sleep problems were associated with delayed onset of PTSS, interventions to address lingering sleep problems might be beneficial for the mental health of older disaster survivors.

Statement of Significance

This study took advantage of a unique opportunity to examine the bidirectional relationships between sleep problems and post-traumatic stress symptoms (PTSS) in the wake of a disaster, using data from older survivors of the 2011 Great East Japan Earthquake and Tsunami, in which sleep quality was assessed 7 months before the disaster. We found evidence for both directions of association; those who slept well before the disaster were less likely to develop PTSS, while those who slept well after the disaster were more likely to recover from PTSS. Given that more than 10% of older survivors still experience PTSS after a decade, interventions to address lingering sleep problems might be beneficial for the mental health of disaster survivors.

Introduction

Sleep is a key contributor to personal health and well-being. Studies have shown that inadequate sleep or sleep disorders have detrimental effects on a wide range of health outcomes, including obesity [1], hypertension [2], diabetes [3], cardiovascular disease [4], and mortality [5]. Sleep problems are frequently observed following traumatic experiences, especially for those suffering from post-traumatic stress disorders (PTSD) [6]. PTSD involves responses to a traumatic event that persist maladaptively, characterized by intrusive thoughts related to the event, avoidance of reminders of the event, negative mood and cognitions, and heightened arousal and reactivity [7]. About 70% of people with PTSD also have cooccurring sleep problems; individuals with PTSD report greater trouble initiating (41% vs. 13%) and maintaining (47% vs. 18%) sleep compared to those without PTSD [8].

Long follow-up of natural disaster survivors suggests that people can recover from post-traumatic stress symptoms (PTSS). However, symptoms can also persist for years afterwards. For example, McLaughlin et al. [9] found that the majority of adults who developed PTSD after Hurricane Katrina did not recover within 18–27 months. Of the older survivors of the Great East Japan Earthquake and Tsunami in 2011, 11.1% reported PTSS in 2013, of whom half (58%) had recovered 5 years later, while 4.8% experienced delayed onset (i.e. new PTSS occurring between 2 years and 5 years after disaster) [10].

Although sleep problems are considered a central symptom of PTSD (e.g. nightmares and insomnia), the temporal relationship between sleep and PTSD is not firmly established; it has been suggested that preexisting sleep disturbances may facilitate PTSD onset in response to trauma exposures [11], as well as they may impede recovery from PTSD [12]. Specifically, pre-disaster sleep problems or associated fatigue can deplete the emotional, cognitive, and physical resources required to manage the aftermath of a traumatic experience optimally [13], whereas post-disaster sleep problems are thought to interfere with the brain's ability to process memories and emotions, and slow down the recovery process for those suffering from PTSD [14]. Furthermore, many people with PTSD use alcohol and other substances to cope with sleep disturbances. Rather than helping, these strategies may be counterproductive, aggravating both sleep and PTSD symptoms [15, 16].

In the present study, we took advantage of a unique opportunity to examine the bidirectional relationships between sleep problems and PTSS in the wake of disaster. The Iwanuma Study is a longitudinal cohort of older survivors of the 2011 Great East Japan Earthquake and Tsunami in which sleep quality was assessed 7 months *before* the disaster. Our focus on older adults is motivated

by the observation that Japan has one of the fastest paces of aging in the world, with estimates suggesting that one-third of the population will be 65 years or older by 2050. They are anticipated to be disproportionately affected by disasters due to preexisting chronic conditions, functional limitations, and socioeconomic conditions, and it has been shown that the 2011 Great East Japan Earthquake and Tsunami has impacted various health outcomes among older survivors [17]. In this study, we examined the associations between sleep problems and distinct trajectories of PTSS (*other than* sleep disturbance). Specifically, we sought to understand whether (1) those who already reported sleep problems before the disaster were more likely to develop PTSS, (2) sleep problems after the disaster prevent recovery from PTSS, or (3) increase the risk of later onset of PTSS, and (4) those who recovered from PTSS also recovered from sleep problems (Figure 1).

Methods

Data

Data came from the Iwanuma Study, a part of a nationwide cohort study of Japanese older adults (the Japan Gerontological Evaluation Study: JAGES) [18]. Iwanuma City was one of the study sites of the JAGES cohort located in Miyagi Prefecture, approximately 80 km from the epicenter of the 2011 Great East Japan Earthquake. Importantly, the baseline survey of the Iwanuma Study was conducted in August 2010, 7 months before the disaster, and was a census of all residents aged 65 years or older living in Iwanuma City (n = 8576). Responses on the baseline survey were obtained from 4957 residents (response rate = 57.8%), which is typical for community-based surveys. The questionnaire was completed by the respondents themselves with help of their family members if needed. Field staff visited all households to collect completed questionnaires and identified any missing data. Approximately 10% of participants had difficulty completing the questionnaire independently and had family members complete it on their behalf. Written informed consent was obtained from each respondent. A previous paper compared the characteristics of the Iwanuma study participants to government Census data of older people aged 65 years or older in Iwanuma city [19], which showed that those who participated in the study were more likely to be younger (% 75 years or older was 40.4% vs. 48.1%), and married (71.4% vs. 64.7%), while there was no difference in gender and employment status.

The Great East Japan Earthquake and Tsunami (the Richter scale: 9.0) struck the city on March 11, 2011 and caused devastating damage to the city killing 180 people, damaging 5542 houses, and flooding 48% of the city's land area. The first follow-up survey was conducted in 2013, 2.5 years after the disaster. Of the 4380 eligible survivors who lived in Iwanuma City, 3567 people responded to the mailed survey (follow-up rate: 81.4%). The second follow-up was conducted in 2016, 5.5 years after the disaster (n = 2781; follow-up rate: 78.0%). The latest survey was conducted in 2020, 9 years after the disaster (n = 2033; follow-up rate 73.1%). In the 2010 survey, questions regarding sleep quality were administered to a randomly selected 20% of the cohort participants. In 2013, sleep data was asked for all participants. In the 2020 survey, items from the Athens Insomnia Scale (AIS) were additionally given to 88% of the participants. Three analytical datasets were prepared for each of our hypotheses, (A) 2010 – 2013 follow-up data (n = 835), (B) 2010 – 2013 – 2016 panel data (n = 1938), and (C) 2010 – 2013 – 2016 – 2020 panel data (n = 1788). Since the proportion of participants to whom sleep questionnaires were distributed for each wave differed, we had different analytical samples for each hypothesis. Specifically, since there was no information on who received the questionnaire including the sleep questionnaire, the analytic sample (A) only includes respondents who have answered at least one question on the sleep questionnaire. The analysis sample (B) was restricted to those who provided data on PTSS since multiple imputation needs stratified estimation. Analytic sample (C) consists of all the participants who received sleep questionnaires. The flow of the sampling strategy is summarized in Figure 2. We compared the characteristics of each analytic sample as shown in Supplementary Table 1.

Measurements

Sleep problems

We used data on sleep quality/problems from 2010, 2013, and 2020 surveys. In 2010 and 2013, five indicators of sleep problems were evaluated: short sleep duration, sleep insufficiency, poor sleep quality, insomnia symptoms, and sleep medication use. These questions were derived from the Pittsburgh Sleep Quality Index (PSQI) [20] except for the item on sleep insufficiency. Insomnia symptoms were defined by questions "could not fall asleep within half an hour of going to bed" or "woke up in the middle of the night or early in the morning," with response categories of never, less than once a week, 1 to 2 times a week, and 3 or more times a week. Respondents who experienced the symptoms 3 or more times a week were regarded as suffering from insomnia [21]. Following the lead of a previous study [21], the five indicators were analyzed separately.

In 2020, the 8-item version of the Athens Insomnia Scale AIS) [22] was additionally measured as a global measure of

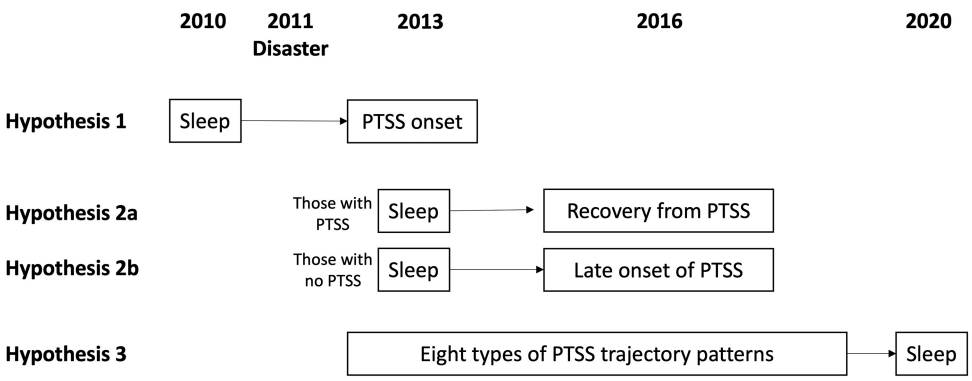


Figure 1. Timeline of the assessment of exposure and outcome for each hypothesis.

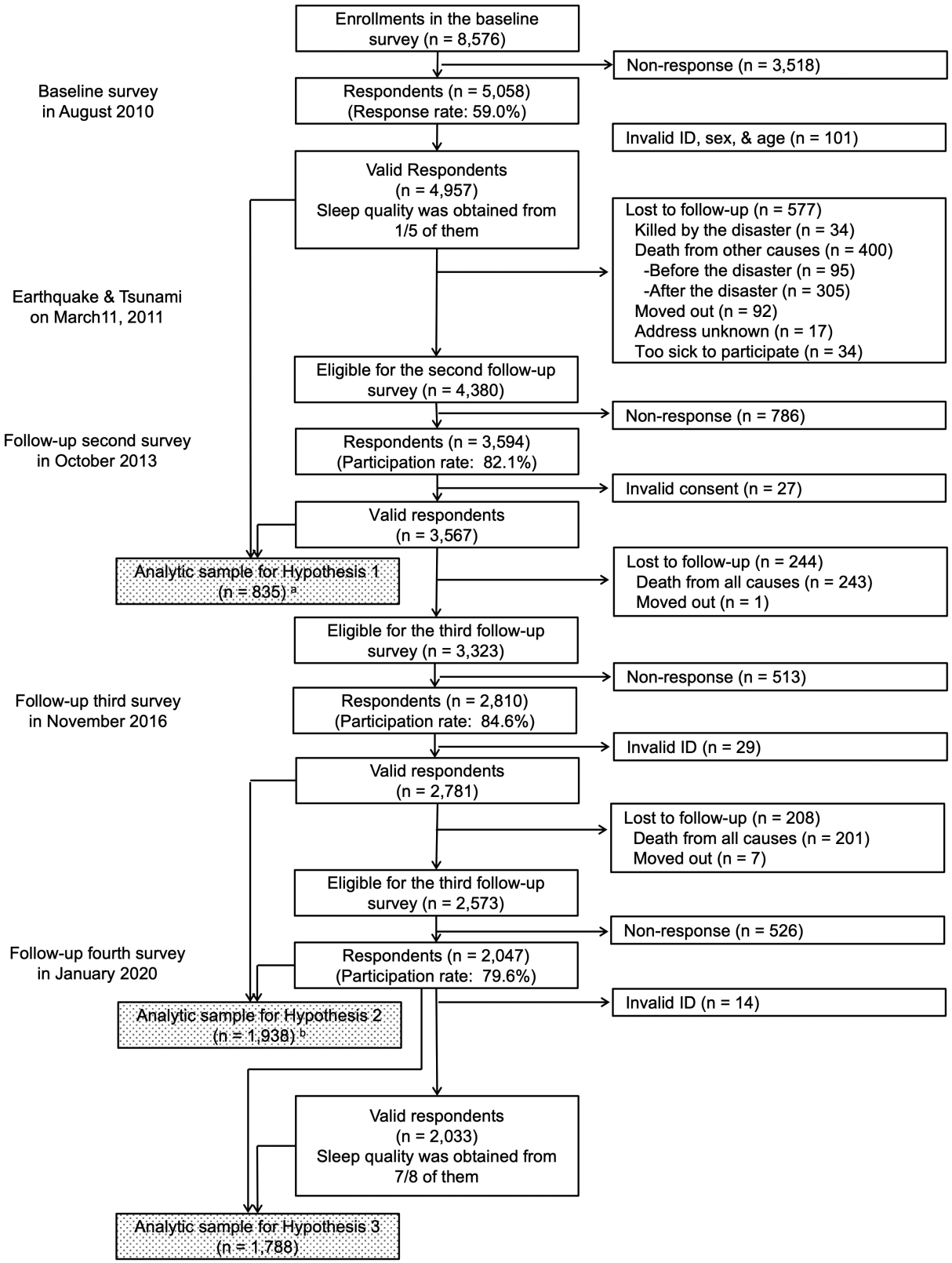


Figure 2. Flow of the analytical sample selection.

[a] Due to the lack of information on who received the questionnaire including the sleep questionnaire, the analytic sample only includes respondents who have answered at least one question on the sleep questionnaire. [b]The analysis was restricted to those who provided data on PTSS since multiple imputation needs stratified estimation.

insomnia. The AIS has been validated in the Japanese population [23]. Insomnia symptoms were defined by eight questions; (1) How quickly did you fall asleep after going to bed?, (2) Did you suddenly wake up during the night?, (3) Did you wake up earlier than you expected?, (4) Did you get plenty of sleep, in terms of total number of hours?, (5) Was the overall quality (as opposed

to the length) of your sleep good?, (6) How did you feel during the day?, and (7) How was your physical and mental strength during the day?, and (8) Were you sleepy during the day? Each question was answered with 4-point Likert response scales. Cronbach's alpha of the AIS-8 has been reported to be 0.89, and its external validity was 0.90 with respect to the total score of the Sleep Problems Scale in the validation study [22, 23]. Cronbach's alpha among this study participants was 0.89. The scores were then summed and categorized into four groups: absence of insomnia (0–5), mild insomnia (6–9), moderate insomnia (10–15), and severe insomnia (16–24) [22]. We constructed a binary variable indicating the presence of insomnia symptoms (i.e. scored 6 or more) for further analyses. We additionally made a binary variable for moderate-to-severe insomnia symptoms (i.e. scored 10 or more) for sensitivity analysis.

Post-traumatic stress symptoms

Post-disaster mental health status was evaluated in 2013, 2016, and 2020. PTSS were evaluated using the Screening Questionnaire for Disaster Mental Health (SQD). The questionnaire was originally developed to screen for PTSS among Japanese older adults affected by the 1995 Hanshin-Awaji Earthquake, and has been validated against the Clinician Administered PTSD Scale and the Impact of Event Scale-Revised [24]. Following previous studies [25], the total score of PTSS was computed minus the two items regarding sleep quality (i.e. having trouble falling asleep or awake in the middle of the night; having nightmares about the earthquake). The responses to each of the nine binary (yes/no) items were summed (range: 0 – 7), and then dichotomized at a cut point of three or more indicating mild-to-severe PTSS. Cronbach's alpha coefficient for SQD has been reported to be 0.83, and its external validity was 0.91 compared to the Clinician Administered PTSD Scale (CASP) for diagnosing PTSD in the validation study [24]. Cronbach's alpha among this study participants was 0.73. Trajectories of PTSS were then categorized into eight groups according to the presence of PTSS in 2013, 2016, and 2020: Never; Delayed onset; Delayed onset but recovered; Persistent across the last two cycles; Early recovery; Fluctuating; Recently recovered since the last survey wave; and Persistent across all waves (see Table 1).

Covariates

Pre-disaster information included age in years, marital status (married or not), educational attainment (9 years or less; 10 to 12 years; 13 years or more), equivalent household income (less than 2 million yen; 2 to 4 million yen; more than 4 million yen [1 million yen = 10 750 USD as of January 1, 2010]), smoking status (never; stopped smoking; current smoker), alcohol consumption (yes; no), number of chronic conditions (no comorbidity; single body system disorder; disorders affecting two body systems; complex multimorbidity, i.e. disorders affecting more than two body systems), and traumatic life events (death of spouse, death of close relatives or friends, and job loss) in the past year (yes; no). Since it is common to have multiple chronic conditions among older people, we evaluated comorbidity status to account for impacts across the different body systems rather than a simple count of chronic conditions/diseases [26]. Supplementary Table 2 shows how we categorized the diseases according to the body systems affected. Traumatic life events included death of spouse, death of close relatives/friends, and job loss in the past year. Due to the limited number of those who experienced multiple events, these were categorized as a binary variable (yes; no). The 2013 post-disaster survey inquired about participants' experience of five types of disaster damages: housing damage (major damage/complete destruction vs. less extensive damage), job loss (yes; no), economic loss (yes; no), loss of relatives (yes; no), and loss of friends (yes; no), number of chronic conditions (no comorbidity; single body system disorder; disorders affecting two body systems; complex multimorbidity, i.e. disorders affecting more than two body systems), and traumatic life events (death of spouse, death of close relatives or friends, and job loss) in the past year (yes; no). Following previous research [20], we did not control for depressive symptoms since sleep problems can be a symptom of depression as well as a risk factor for it [27], while controlling for the score of depressive symptoms and excluded those who answered they are under treatment for depression as a sensitivity analysis for the first hypothesis (i.e. association between pre-disaster sleep problems and onset of PTSS after disaster) ($n = 827$; Supplementary Table 4).

Statistical analysis

Hypothesis (1) Do pre-disaster sleep problems increase the risk of developing PTSS?

Using 2010–2013 data (A) ($n = 835$), we examined whether the pre-disaster sleep problems increase the risk of developing PTSS after the disaster using a Poisson regression analysis with a robust variance estimator [28]. We first fit separate models for the association between each sleep problem and developing PTSS, controlling for pre-disaster age, gender, marital status, education, equivalent income, alcohol consumption, and smoking status, and five types of disaster damages (Table 2). We additionally included interaction terms between each type of disaster damage and sleep problem to investigate if there was effect modification of sleep problems by type of disaster damages (Supplementary Tables 3A–C). Since the numbers of people experienced housing damage and job loss were small to conduct stratified analysis ($n = 10$ and 25, respectively), we conducted the analysis with interaction terms only for loss of relatives, loss of friends, and economic loss.

Hypothesis (2A and 2B) Do sleep problems prevent recovery from PTSS, and/or increase the risk of later onset of PTSS?

Data (B) from 2010 – 2013 – 2016 ($n = 1938$) was split into those who developed PTSS in 2013 ($n = 577$; subsample B1) and those who did not ($n = 1361$; subsample B2) to investigate whether the sleep problems in 2013 prevented recovery from PTSS in 2016 among the subsample B1 and/or increased the risk of delayed onset of PTSS in 2016 among the subsample B2. We used a Poisson regression analysis with a robust variance estimator controlling for pre-disaster age, gender, marital status, education, equivalent income, alcohol consumption, smoking status, and five types of disaster damage.

Hypothesis (3) Do individuals who recover from PTSS also recover from sleep problems?

Finally, we used 2010–2013–2016–2020 panel data (C) ($n = 1788$) to investigate how PTSS trajectories from 2013 to 2020 are associated with sleep problems in 2020. We investigated the association between different types of PTSS trajectory (Never, Delayed onset, Delayed onset but recovered, Persistent across the last two cycles, Early recovery, Fluctuating, Recently recovered since the last survey wave, and Persistent across all waves), and sleep quality in 2020, controlling for pre-disaster characteristics (i.e. age, gender,

Table 1. Participants' Characteristics by Post-traumatic Stress Symptoms Trajectory (*n* = 1788)

	Did not have PTSS in 2013			Had PTSS in 2013					Total
	Never (*n* = 849)	**Delayed onset (*n* = 134)**	**Delayed onset but recovered (*n* = 183)**	**Persistent across the last two cycles (*n* = 111)**	**Early recovery (*n* = 144)**	**Fluctuating (*n* = 70)**	**Recently recovered since the last survey wave (*n* = 116)**	**Persistent across all waves (*n* = 181)**	
PTSS 2013					x	x	x	x	
PTSS 2016			x	x			x	x	
PTSS 2020		x		x		x		x	
Variables from 2010									
Age	71.2 [5.0]	72.2 [4.8]	72.6 [5.6]	73.6 [5.6]	72.2 [5.3]	71.3 [4.9]	73.1 [5.9]	72.7 [5.3]	71.9 [5.2]
Gender (Male)	446 (52.5)	60 (44.8)	73 (39.9)	43 (38.7)	51 (35.4)	27 (38.6)	29 (25.0)	54 (29.8)	783 (43.8)
Married (*n* = 1744)	654 (78.6)	108 (80.6)	137 (77.0)	77 (72.0)	109 (77.3)	55 (78.6)	80 (73.4)	120 (69.4)	1,340 (76.8)
Education (*n* = 1748)									
<10 years	202 (24.3)	43 (32.1)	68 (38.2)	46 (43.4)	47 (32.9)	25 (36.2)	41 (36.0)	70 (40.9)	542 (31.0)
10–12 years	419 (50.3)	62 (46.3)	79 (44.4)	44 (41.5)	65 (45.5)	34 (49.3)	50 (43.9)	72 (42.1)	825 (47.2)
>12 years	212 (25.5)	29 (21.6)	44 (41.5)	16 (15.1)	31 (21.7)	10 (14.5)	23 (20.2)	29 (17.0)	381 (21.8)
Equivalized income (Yen) (*n* = 1529)									
<2.00 million	325 (43.4)	59 (50.4)	71 (49.7)	46 (52.9)	47 (37.9)	34 (57.6)	47 (49.0)	91 (50.1)	720 (47.1)
2.00–4.00	333 (44.5)	48 (41.0)	58 (40.6)	31 (35.6)	66 (53.2)	22 (37.3)	42 (43.8)	53 (34.4)	653 (42.7)
>4.00 million	91 (12.2)	10 (8.6)	14 (9.8)	10 (11.5)	11 (8.9)	3 (5.1)	7 (7.3)	10 (6.5)	156 (10.2)
Smoking (*n* = 1672)									
Never	469 (57.6)	72 (57.1)	107 (65.6)	76 (73.1)	83 (63.9)	42 (63.6)	80 (75.5)	119 (73.5)	1,048 (62.7)
Stopped	249 (30.6)	38 (30.2)	39 (23.9)	20 (19.2)	38 (29.2)	17 (25.8)	18 (17.0)	32 (19.8)	451 (27.0)
Currently smokes	97 (11.9)	16 (12.7)	17 (10.4)	8 (7.7)	9 (6.9)	7 (10.6)	8 (7.6)	11 (6.8)	173 (10.4)
Alcohol (Yes) (*n* = 1763)	412 (49.0)	52 (38.8)	67 (37.6)	31 (29.0)	46 (32.2)	27 (39.1)	30 (25.9)	49 (28.0)	714 (40.5)
Chronic conditions (*n* = 1323)									
No issue	38 (6.4)	5 (5.4)	12 (8.4)	9 (10.2)	10 (9.4)	4 (7.7)	10 (11.1)	8 (5.3)	96 (7.3)
Single body system disorder	298 (49.8)	48 (51.6)	69 (48.3)	43 (48.9)	53 (49.5)	24 (46.2)	32 (35.6)	61 (40.1)	628 (47.5)
Two body system disorders	151 (25.3)	23 (24.7)	34 (23.8)	17 (19.3)	28 (26.2)	18 (34.6)	27 (30.0)	40 (26.3)	338 (25.6)
Complex multimorbidity	111 (18.6)	17 (18.3)	28 (19.6)	19 (21.6)	16 (15.0)	6 (11.5)	21 (23.3)	43 (28.3)	261 (19.7)
Had traumatic life events in the past year	299 (36.6)	39 (29.6)	63 (37.5)	36 (36.4)	49 (35.5)	23 (34.3)	41 (38.0)	73 (44.8)	623 (36.8)
Variables from 2013									
Chronic conditions (*n* = 1295)									
No issue	32 (5.4)	14 (15.1)	10 (7.3)	8 (9.3)	11 (10.9)	3 (5.9)	8 (9.2)	7 (4.7)	93 (7.2)
Single body system disorder	260 (44.0)	37 (39.8)	48 (34.8)	39 (45.4)	38 (37.6)	23 (45.1)	28 (32.2)	42 (28.4)	515 (39.8)
Two body system disorders	189 (32.0)	23 (24.7)	56 (40.6)	22 (25.6)	32 (31.7)	17 (33.3)	26 (29.9)	63 (42.6)	428 (33.1)
Complex multimorbidity	110 (18.6)	19 (20.4)	24 (17.4)	17 (19.8)	20 (19.8)	8 (15.7)	25 (28.7)	36 (24.3)	259 (20.0)
Had traumatic life events in the past year	336 (39.6)	53 (39.6)	66 (36.1)	44 (39.6)	60 (41.7)	30 (42.9)	55 (47.4)	88 (48.6)	732 (40.9)

Table 1. Continued

	Did not have PTSS in 2013			Had PTSS in 2013					Total
	Never (*n* = 849)	Delayed onset (*n* = 134)	Delayed onset but recovered (*n* = 183)	Persistent across the last two cycles (*n* = 111)	Early recovery (*n* = 144)	Fluctuating (*n* = 70)	Recently recovered since the last survey wave (*n* = 116)	Persistent across all waves (*n* = 181)	
Disaster damages									
Major housing damage (*n* = 1749)	35 (4.2)	8 (6.1)	14 (7.8)	7 (6.4)	13 (9.8)	13 (19.7)	11 (9.8)	33 (18.9)	134 (7.7)
Lost relatives	199 (23.4)	40 (29.9)	50 (27.3)	33 (29.7)	53 (36.8)	23 (32.9)	44 (37.9)	77 (42.5)	519 (29.0)
Lost friends	131 (15.4)	24 (17.9)	29 (15.9)	14 (12.6)	32 (22.2)	18 (25.7)	22 (19.0)	38 (21.0)	308 (17.2)
Economic loss (*n* = 1756)	118 (14.0)	21 (15.8)	36 (19.9)	21 (19.4)	38 (28.4)	32 (47.8)	41 (36.6)	98 (55.7)	405 (23.1)
Job loss (n = 1,571)	39 (5.1)	4 (3.3)	8 (5.1)	4 (4.3)	7 (6.0)	12 (19.1)	10 (10.0)	21 (14.1)	105 (6.7)
Variables from 2020									
Sleep quality in 2020									
>Mild insomnia by AIS	194 (22.9)	59 (44.0)	64 (35.0)	65 (58.6)	48 (33.3)	40 (57.1)	41 (35.3)	108 (59.7)	619 (34.6)
>Moderate insomnia by AIS	70 (8.2)	23 (17.2)	29 (15.9)	36 (32.4)	14 (9.7)	17 (24.3)	21 (18.1)	70 (38.7)	280 (15.7)
Short sleep	64 (7.5)	14 (10.5)	18 (9.8)	12 (10.8)	7 (4.9)	9 (12.9)	12 (10.3)	22 (12.2)	158 (8.8)
Insomnia symptoms (*n* = 1737)	380 (45.0)	62 (49.2)	82 (46.6)	63 (57.8)	60 (43.5)	27 (41.5)	49 (45.0)	98 (57.7)	821 (47.3)
Sleep insufficiency (*n* = 1739)	91 (10.8)	20 (15.6)	23 (13.1)	25 (22.9)	16 (11.6)	12 (17.9)	17 (15.5)	40 (23.7)	244 (14.0)
Poor sleep quality (*n* = 1742)	191 (22.6)	36 (28.6)	56 (31.6)	52 (49.1)	30 (21.6)	28 (41.2)	31 (27.9)	70 (40.9)	494 (28.4)
Sleep medication use (*n* = 1745)	126 (14.9)	30 (23.8)	38 (21.5)	37 (34.3)	28 (20.1)	18 (26.5)	35 (31.5)	58 (33.9)	370 (21.2)

Age, gender, marital status, education, equivalent income, smoking status, and alcohol consumption were evaluated in 2010, while disaster damages were evaluated in 2013, and sleep quality was evaluated in 2020.

marital status, education, equivalent income, smoking status, and alcohol consumption) and five types of disaster damage, using a Poisson regression with a robust variance estimator. Since there were seven outcomes, we employed the Bonferroni correction to ensure conservative results; p value < 0.007 was set as the threshold for statistical significance.

Missing values of the questions were imputed by the Markov chain Monte Carlo methods to generate 20 data sets [29]. Missing data were imputed separately for datasets (A), (B) and (C), respectively. All statistical analyses were conducted using Stata 16.1 (StataCorp, College Station, TX, USA).

Results

Table 1 summarizes the characteristics of the analytic sample (C) stratified by PTSS trajectory. The mean age of the participants was 71.9 years (SD 5.2), with 43.8% being males. Among 1788 participants, 849 (47.5 %) had not experienced PTSS at all, while 181 (10.1%) experienced persistent PTSS during the decade following the earthquake and tsunami. Disaster experience largely differed by the PTSS trajectory patterns; for example, major housing damage was observed for 4.2% of those who had not experienced PTSS at all while it was 18.9% for those who experienced persistent PTSS. In 2020, 34.6% and 15.7% of the participants showed > mild and > moderate insomnia defined by AIS, respectively. When we turn to each type of sleep problem separately, there was a wide range of prevalence, with 8.8% reporting short sleep duration while 47.3% reporting insomnia symptoms, which was defined by the two questions in the PSQI. Figure 3 illustrates the prevalence of each sleep problem in 2020 by the PTSS trajectory patterns.

Table 2 summarizes the results of regression analysis linking pre-disaster sleep problems to the onset of PTSS after the disaster using 2010–2013 data (n = 835). We found that sleep insufficiency (PR = 1.40, 95% confidence intervals [CI] 1.09, 1.80) as well as experiences of losing relatives, friends, and money in the earthquake and tsunami were independently associated with a higher risk of developing PTSS in 2013. However, we did not find evidence of effect modification of the association between pre-disaster

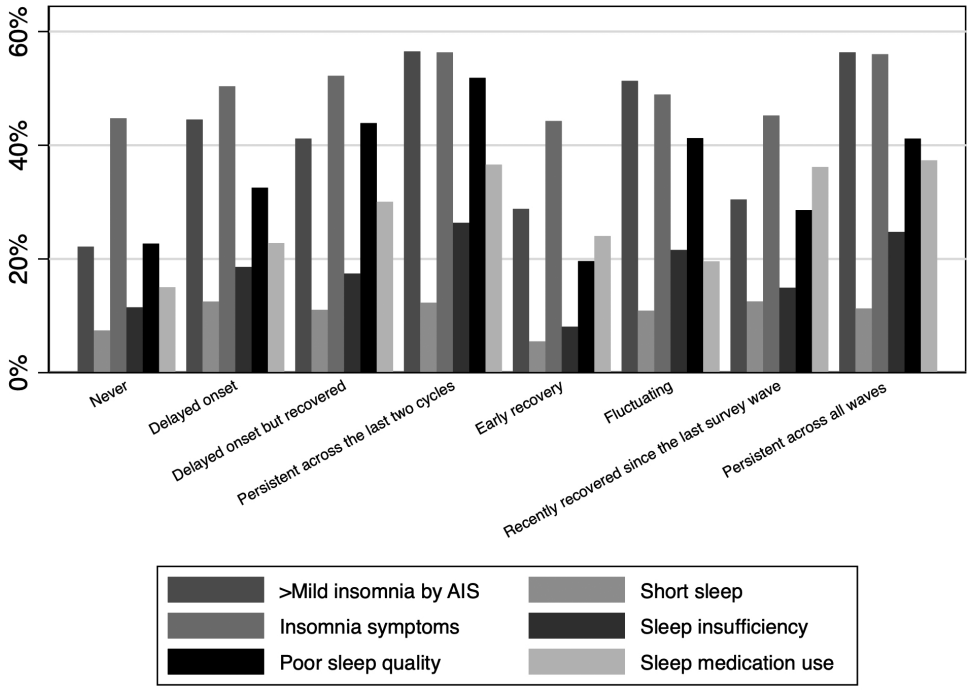


Figure 3. Prevalence of each sleep problem in 2020 stratified by the experienced post-traumatic stress symptoms trajectory.

Table 2. Sleep Problems in 2010, Disaster Experience and Onset of PTSS in 2013 (n = 835)

	Model 1	Model 2	Model 3	Model 4	Model 5
Short sleep duration in 2010	1.03 (0.73, 1.43)				
Insomnia symptoms in 2010		1.18 (0.93, 1.49)			
Sleep insufficiency in 2010			1.40 (1.09, 1.80)		
Poor sleep quality in 2010				1.24 (0.98, 1.57)	
Sleep medication use in 2010					1.23 (0.94, 1.61)
Major housing damage	0.59 (0.19, 1.83)	0.57 (0.18, 1.78)	0.57 (0.19, 1.74)	0.58 (0.19, 1.77)	0.61 (0.20, 1.89)
Lost relatives	1.37 (1.07, 1.75)	1.37 (1.07, 1.75)	1.37 (1.07, 1.75)	1.37 (1.07, 1.76)	1.38 (1.08, 1.76)
Lost friends	1.84 (1.40, 2.43)	1.86 (1.41, 2.45)	1.79 (1.36, 2.36)	1.83 (1.39, 2.41)	1.82 (1.38, 2.40)
Economic loss	2.48 (1.97, 3.12)	2.44 (1.94, 3.08)	2.43 (1.93, 3.06)	2.41 (1.90, 3.04)	2.48 (1.97, 3.12)
Job loss	0.73 (0.34, 1.60)	0.73 (0.34, 1.61)	0.74 (0.34, 1.62)	0.74 (0.34, 1.62)	0.74 (0.34, 1.60)

Prevalence ratios and 95% confidence intervals are shown. Covariates were evaluated in 2010, which include age, gender, marital status, education, equivalent income, alcohol consumption, smoking status, number of chronic conditions, and traumatic life events in the past year.

Table 3. Sleep Problems in 2013 and Recovery from PTSS by 2016 Among Those Who Experienced PTSS as of 2013 (n = 577)

	Model 1	Model 2	Model 3	Model 4	Model 5
Short sleep duration in 2013	0.87 (0.62, 1.22)				
Insomnia symptoms in 2013		0.82 (0.66, 1.02)			
Sleep insufficiency in 2013			0.83 (0.59, 1.17)		
Poor sleep quality in 2013				0.77 (0.62, 0.96)	
Sleep medication use in 2013					0.85 (0.65, 1.11)

Prevalence ratios and 95% confidence intervals are shown. Covariates were evaluated in 2010, which includes age, gender, marital status, education, equivalent income, alcohol consumption, smoking status, number of chronic conditions and number of traumatic life events in the past year and disaster damages, number of chronic conditions, and number of traumatic life events in the past year measured in 2013.

sleep quality and PTSS onset by any type of disaster damage (Supplementary Tables 3A–C).

Table 3 summarizes the results of regression analysis linking sleep problems in 2013 to recovery from PTSS by 2016 among individuals who reported suffering from PTSS in 2013 (n = 577), while Table 4 shows the association of sleep problems with delayed onset of PTSS (in 2016) among those who were free from PTSS in 2013 (n = 1361). Individuals with poor sleep quality (PR = 0.77, 95%

Table 4. Sleep Problems in 2013 and Delayed Onset of PTSS by 2016 Among Those Who Were Free from PTSS as of 2013 (n = 1361)

	Model 1	Model 2	Model 3	Model 4	Model 5
Short sleep duration in 2013	1.95 (1.31, 2.89)				
Insomnia symptoms in 2013		1.16 (0.84, 1.61)			
Sleep insufficiency in 2013			1.14 (0.72, 1.80)		
Poor sleep quality in 2013				1.34 (0.98, 1.83)	
Sleep medication use in 2013					1.30 (0.92, 1.85)

Prevalence ratios and 95% confidence intervals are shown. Covariates were evaluated in 2010, which includes age, gender, marital status, education, equivalent income, alcohol consumption, smoking status number of chronic conditions traumatic life events in the past year and disaster damages, number of chronic conditions, and traumatic life events in the past year measured in 2013.

Table 5. PTSS Trajectory After the Disaster and Sleep Problems in 2020 (n = 1788)

	>Mild insomnia by AIS	>Moderate insomnia by AIS	Short sleep duration	Insomnia symptoms	Sleep insufficiency	Poor sleep quality	Sleep medication use
Ref. Never	PR (95% CI)	PR (95% CI)	PR (95% CI)	PR (95% CI)	PR (95% CI)	PR (95% CI)	PR (95% CI)
Delayed onset	1.76 (1.36, 2.29)*	1.43 (0.76, 2.67)	1.05 (0.55, 2.00)	1.04 (0.85, 1.28)	1.26 (0.79, 2.01)	1.36 (1.02, 1.82)	1.46 (1.02, 2.09)
Delayed onset but recovered	1.50 (1.08, 2.07)	1.67 (0.89, 3.13)	1.22 (0.63, 2.34)	1.06 (0.85, 1.32)	0.82 (0.40, 1.68)	1.36 (0.99, 1.87)	1.28 (0.83, 1.97)
Persistent across the last two cycles	2.16 (1.59, 2.92)*	2.98 (1.69, 5.25)*	1.29 (0.60, 2.78)	1.20 (0.93, 1.55)	1.81 (1.06, 3.10)	1.87 (1.33, 2.63)*	1.85 (1.23, 2.78)*
Early recovery	1.42 (1.08, 1.87)	0.90 (0.46, 1.74)	0.89 (0.48, 1.65)	0.96 (0.79, 1.17)	1.13 (0.71, 1.80)	1.01 (0.73, 1.40)	1.41 (1.02, 1.96)
Fluctuating	2.12 (1.61, 2.78)*	2.54 (1.45, 4.43)*	1.32 (0.70, 2.48)	1.01 (0.77, 1.31)	1.48 (0.85, 2.59)	1.49 (1.08, 2.06)	1.43 (0.93, 2.21)
Recently recovered since the last survey wave	1.36 (0.95, 1.95)	1.36 (0.68, 2.73)	1.45 (0.78, 2.70)	1.06 (0.83, 1.35)	1.47 (0.88, 2.45)	1.20 (0.83, 1.75)	1.41 (0.94, 2.11)
Persistent across all waves	2.13 (1.72, 2.64)*	3.18 (2.15, 4.70)*	1.18 (0.70, 1.99)	1.11 (0.93, 1.32)	1.77 (1.23, 2.55)*	1.49 (1.17, 1.90)*	1.93 (1.45, 2.56)*

Prevalence ratios (PR) and 95% confidence intervals (CI) are shown. Covariates include age, gender, marital status, education, equivalent income, smoking status, alcohol consumption, number of chronic conditions and traumatic life events in the past year measured in 2010 and disaster damages, number of chronic conditions, and traumatic life events in the past year measured in 2013. The effect sizes that demonstrated statistically significant associations with sleep problems after Bonferroni correction are indicated with "*.".

CI 0.62, 0.96) were significantly less likely to recover from PTSS, while those with short sleep duration (PR = 1.95, 95% CI 1.31, 2.89) were more likely to experience delayed onset of PTSS after 5 years.

Table 5 shows the results of regression analysis linking different types of PTSS trajectory (2013 – 2016 – 2020) to sleep problems in 2020 (n = 1788). As indicated by the model with insomnia defined by AIS, compared to those who never experienced PTSS, those with persistent PTSS were more likely to report insomnia (PR = 2.13, 95% CI, 1.72, 2.64 for > mild insomnia; PR = 3.18, 95% CI 2.15, 4.70 for > moderate insomnia), as well as those with PTSS persistent across the last two cycles (PR = 2.16, 95% CI, 1.59, 2.92 for > mild insomnia; PR = 2.98, 95% CI 1.69, 5.25 for > moderate insomnia) and those who have fluctuating pattern of PTSS (PR = 2.12, 95% CI, 1.61, 2.78 for > mild insomnia; PR = 2.54, 95% CI 1.45, 4.43 for > moderate insomnia) were more likely to have sleeping problems even after Bonferroni correction ($p < 0.007$). On the other hand, while they still have some sleep problems (e.g. PR for > mild insomnia = 1.42 for early recovery and 1.50 for delayed onset but recovered), those who recovered from PTSS were less likely to report most of sleep problems, and none of the sleeping problems were found to be significantly prevalent among those who had recovered from PTSS after Bonferroni correction. Those who suffered from persistent PTSS from 2013 were more likely to report poor sleep quality (PR = 1.87, 95% CI 1.33, 2.63), and sleep medication use (PR = 1.85, 95% CI 1.23, 2.78). We found no difference in the problems of short sleep duration and insomnia symptoms defined by two questions from PSQI according to the type of PTSS trajectory after the disaster.

Discussion

Summary of findings

Using long-term (i.e. 9 years) follow-up data of older survivors of the Great East Japan Earthquake and Tsunami, the present study investigated the bidirectional associations between PTSS and sleep quality. We found that (1) those who already had sleep insufficiency before the disaster were more likely to develop PTSS even in the absence of concrete disaster damages, (2) those with poor sleep quality were less likely to recover from PTSS in the aftermath of disaster, (3) short sleep duration was associated with increased risk of delayed onset of PTSS 5 years after the disaster, and (4) compared to those who never had PTSS, those who had PTSS throughout the post-disaster period were more likely to suffer from sleep problems, and even those who recovered from PTSS still had slightly higher PR for sleep problems 9 years after the disaster.

Do pre-disaster sleep problems increase the risk of developing PTSS?

While some studies reported a high prevalence of sleep problems among disaster survivors [30, 31], a unique strength of this study is that we utilized *pre-disaster* sleep quality data to investigate the association with post-disaster PTSS onset. We found that individuals reporting sleep problems before the disaster were more likely to develop PTSS controlling for pre-disaster covariates, which however did not amplify the impact of disaster damages on PTSS onset (i.e. no effect modification was detected between

disaster damages and sleep problems). The result indicates that sleep problems are independent risk factors for PTSS regardless of the experience of disaster damage.

The finding is in line with some studies. For example, Bryant et al. [13] investigated how sleep disturbance in the period before a traumatic event predicted the onset of psychiatric disorder in a hospital-based study. Patients were asked to recall sleep problems immediately preceding their injury and hospitalization. Results showed that patients who had sleep disturbances prior to the injury were more likely to have a psychiatric disorder after 3 months (odds ratio [OR] = 2.44, 95% CI 1.62, 3.69). However, sleep disturbance before the trauma was based on retrospective bias, so that information bias could not be ruled out. Wang et al. [32] found that pre-deployment insomnia was associated with an increased risk of post-deployment PTSD (OR = 3.14, 95% CI 2.58, 3.82) among the US Army soldiers deployed to Afghanistan. Similarly, Gehrman et al. [33] have shown that those who reported insomnia symptoms prior to deployment had increased odds of developing PTSD using data from the Millennium Cohort Study in the United States. They also found no effect modification between insomnia symptoms and combat exposure.

A possible explanation for these findings is that sleep problems are a marker of pre-disaster mental illness, particularly depression [34, 35]. When we additionally controlled for pre-disaster depression and excluded those who were under treatment for depression (Supplementary Table 4), our findings attenuated to the level of statistical insignificance ($p > 0.05$), but the trend remained essentially unchanged. Hence, the association between pre-disaster sleep problems and post-disaster PTSS is unlikely to be explained fully by the confounding by pre-disaster depressive illness. Additionally, given that there was no effect modification of the association between sleep problems and PTSS by types of disaster damage, it seems that those who had pre-disaster sleep problems showed PTSS regardless of the actual experience of damages. One potential explanation is REM sleep, which is known to be involved in the consolidation of memory and play an important role in emotional processing and regulation [36]. It has been proposed that REM fragmentation may play a role in the development of PTSD [37, 38]; for example, Mellman et al. [37] found more wake time among those who have traumatic events compared to those who were free from such experiences and PTSD onset was associated with shorter and fragmented REM sleep. Cognitive mechanisms may also be involved, such as rumination or low coping skills [39], which could be associated with both sleep problems and higher sensitivity to direct disaster exposure. Michael et al. [39] showed that rumination was linked to both reduced coping and triggering of intrusive memories, while persistent, unproductive thoughts (characteristic of rumination) were associated with PTSD onset. Sleep disturbances can also affect the regulation of stress hormones, such as adrenocorticotropic hormone and cortisol, which can contribute to the development of PTSD [40].

Do post-disaster sleep problems prevent recovery from PTSS, or increase the risk of later onset of PTSS?

By stratifying the analysis for survivors who did/did not report PTSS in 2013, we further investigated the association between sleep problems in 2013 and recovery/delayed onset of PTSS in 2016. Results showed that those with insomnia symptoms and poor sleep quality were less likely to recover from PTSS after 5 years, while those with short sleep duration and poor sleep quality were more likely to experience delayed onset of PTSS controlling for pre-disaster variables. It is possible that individuals who suffered PTSS and sleep problems simultaneously (i.e. severe PTSD) in 2013 tended to have long-lasting symptoms. However, given that some intervention studies have shown a beneficial impact of sleep treatment on PTSD symptoms [41, 42], it is suggested that sleep quality has an impact on improving or worsening PTSS.

Do individuals who recover from PTSS also recover from sleep problems?

Finally, we investigated the (reverse) association between PTSS trajectories after the disaster and sleep problems in 2020. We found weak evidence that there was a certain amount of people with PTSS who chronically suffer from sleeping problems after 9 years, and those who recovered from PTSS still tend to have sleeping problems compared to those who never had PTSS. This may indicate a long-lasting impact of the earthquake on sleep quality among many people including those who have less affected. While previous studies had suggested a long-lasting impact of the earthquake on sleep, e.g. Tempesta et al. [43] have shown that survivors of L'Aquila earthquake in Italy had lower sleep quality after 2 years compared to those who lived far from the epicenter, this study reveals that it can be even longer. It is also possible that the finding indicates higher coping skills among those who never developed PTSS.

In this study, PTSS after the earthquake was mainly associated with insomnia defined by AIS, poor sleep quality, and sleep medication use. While we used two indicators of insomnia symptoms due to the different data availability in each survey (i.e. AIS and two questions from PSQI), they showed quite different results in relation to PTSS. Picking a few items from an established questionnaire (e.g. PSQI) to informally assess insomnia symptoms might not have been the optimal approach. Short sleep duration was not associated with PTSD in most models, possibly because it is less of a problem in an older population where people can get sleep during the day.

Limitations

There are some limitations to be noted. As shown in Supplementary Table 1, participants in analytic data (A) were less likely to experience disaster damages compared to (B) and (C). This seems to be because those who did not answer any of the sleep questions were more likely to have experienced disaster damages and were excluded from the analyses because of the lack of information on the sleep question. Additionally, relatively small sample size for the analytic data (A) may have limited the statistical power for analyses with interaction terms between disaster damages and sleep problems. Second, we have no information on PTSS before the earthquake. However, the post-traumatic symptoms assessed in this study were specifically addressed to experiences of the disaster, and thus we can assume that any symptoms reported in 2013 were of new onset. Third, sleep problems were self-reported. While the questionnaires were validated against clinical diagnoses, objective measures of sleep quality (e.g. polysomnography) would have been helpful. Fourth, given that 29% of the study participants had already reported depressive symptoms prior to the disaster, medication for depression might have affected sleep quality. We did not collect specific data on medication for chronic conditions, which may directly affect sleep quality either through pain or other symptoms. Fifth, since the baseline survey was conducted as a census of all residents aged 65 years or older in Iwanuma City (i.e. no exclusion criteria

other than age), it is possible that the quality of data was lower for those with cognitive decline or extremely low educational background. Additionally, the self-report nature of the survey may have resulted in misreporting, particularly given that our sample consisted of older adults. We could not address this issue because we do not have information on how much time respondents spent in completing the questionnaire. Sixth, selective attrition due to loss to follow-up may have resulted in selection bias [44]. Given the length of follow-up of older survivors (10 years in total), those who were more severely impacted by the disaster damage might have died earlier. We have provided the characteristics of the participants who were lost to follow-up (in Supplementary Table 5), which suggested that those who were older, unmarried, had lower education and income, consumed less alcohol, and had comorbidities tended to have been lost to follow-up, but there was no systematic tendency in sleep problems/PTSS. Lastly, the findings may not be generalizable to other age groups. Research suggests that older adults typically exhibit greater emotional regulation and resilience [45, 46], while they tend to have a higher incidence of sleep problems compared to younger adults [47] and a higher risk of having PTSD [48]. Additionally, social support by the government and society in the context of the Great East Japan Earthquake may have modified the relationship between sleep and PTSS; hence, the results may not be generalizable to other settings where social support is limited [49].

Conclusion

Taking advantage of the unique availability of pre-disaster information on sleep quality, as well as repeated assessments during post-disaster follow-up, the present study assessed the bidirectional associations between PTSS and sleep quality among older disaster survivors. We found evidence for both directions of association; those who slept well before the disaster were less likely to develop PTSS while those slept well after the disaster were more likely to recover from PTSS. Given that more than 10% of older survivors still suffer from PTSS after a decade, and that sleep problems were associated with delayed onset of PTSS even for those who were initially free from PTSS after the disaster, interventions to address lingering sleep problems might be beneficial for the mental health of disaster survivors. Given that previous studies have shown that treating PTSD alone does not resolve comorbid sleep problems [50], it is suggested that integrative treatment for sleep disturbances should be provided together with PTSS treatment, rather than considering post-disaster sleep problems as an aspect of PTSS.

Supplementary Material

Supplementary material is available at *SLEEP* online.

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Disclosure Statement

None declared.

Ethical Approval

The study was approved by the Human Subjects Committee of the Harvard T.H. Chan School of Public Health (CR-23143-09), and the Institutional Review Boards of Chiba University (protocol #3442), and Tokyo Medical and Dental University (D2021-025).

Data Availability

The data underlying this article cannot be shared publicly since the Iwanuma Study was conducted within a single geographical location, which increases the risk of breach of confidentiality. The data will be provided on reasonable request to the principal investigator of the parent cohort (K.K.: kkondo@chiba-u.jp) and the Iwanuma Study principal investigator (I.K.: ikawachi@hsph.harvard.edu).

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