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Association between changes in walking time and all-cause mortality among survivors of the Great East Japan Earthquake: the Research Project for Prospective Investigation of Health Problems Among Survivors of the Great East Japan Earthquake and Tsunami Disaster (RIAS) study

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ABSTRACT

Introduction Several studies have investigated the association between physical activity (PA) and all-cause mortality. However, no study has systematically examined the association between PA changes and all-cause mortality among residents of disaster-stricken areas. This study aimed to clarify the association between PA changes and the risk of all-cause mortality among survivors of the Great East Japan Earthquake.

Methods At two time points from 2011 to 2012, 2138 men and 3683 women responded to a question about walking time. The cut-off value was set at 30 min, and PA changes were evaluated using responses regarding walking time over 2 years. Participants were classified into four groups according to PA changes: high stable, increasing, decreasing and low stable. Using a Cox regression model, multivariate-adjusted HRs and 95% CIs for all-cause mortality, according to PA changes, were calculated after adjusting for age, area, smoking status, drinking status, grip strength, psychological distress, obesity, hypertension, diabetes, dyslipidaemia, residential status and current job status.

Results During the 5-year follow-up, 241 deaths occurred. Compared with that of the high stable group, the decreasing group had a higher risk of all-cause mortality; multivariate-adjusted HRs were 2.40 and 2.43 for men and women, respectively. Among women, the low stable group also had a higher risk of all-cause mortality compared with that of the high stable group.

Conclusion Our findings indicate the importance of assessing PA and creating an environment to allow its maintenance as early as possible after large-scale natural disasters.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Sudden environmental changes after a large natural disaster affect the physical activity (PA) of survivors.
⇒ Previous studies investigating the association between PA changes and all-cause mortality in the general population have revealed the association between decreased PA and all-cause mortality.
⇒ No previous study focused on survivors has investigated the association between PA changes and all-cause mortality.

INTRODUCTION

Physical activity (PA) is any bodily movement produced by skeletal muscles that results in energy expenditure.[1] PA is associated with all-cause mortality.[2–6] Lee *et al* demonstrated that PA accounted for approximately 9% of premature mortality in 2008.[7] However, most of these findings are based on studies using a single measurement of PA, and the dynamic nature of PA owing to sudden environmental changes has not been considered.

On 11 March 2011, a massive 9.0-magnitude earthquake struck Japan's northeastern coast. The Great East Japan Earthquake (GEJE) and tsunami caused extensive damage, with 19 775 individuals confirmed dead and 2550 missing (8 March 2024).[8] Iwate Prefecture is located in the Tohoku area in the northern part of Honshu, Japan's largest island. Yamada

WHAT THIS STUDY ADDS

⇒ We assessed PA changes among the survivors of the Great East Japan Earthquake over 2 years, and PA changes classified into four categories were investigated for association with all-cause mortality.
⇒ Decreased PA after a disaster significantly increased the risk of all-cause mortality.
⇒ Participants with decreased PA in the first year after a disaster had a higher risk of all-cause mortality, even if PA improved in the next year, compared with that of those who maintained PA over the 2 years.
⇒ Participants in temporary housing had a higher risk of all-cause mortality than that of those not in temporary housing.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ This study is important for furthering our understanding of the role of PA changes after a large natural disaster.
⇒ To prevent long-term mortality after a disaster, PA changes should be assessed.
⇒ It is crucial to provide an environment where PA can be maintained to prevent long-term mortality risk in disaster areas.

Town, Otsuchi Town and Rikuzentakata City were heavily damaged by the earthquake and the tsunami. Eight hundred and twenty people died or were missing in Yamada, 1286 in Otuchi and 1813 in Rikuzentakata (1 September 2013), which accounted for 4.4%, 8.4% and 7.8% of the total population in each municipality, respectively. Rikuzentakata had a high percentage of older people and had the largest area flooded by the tsunami (5.6% of the city area). In Otuchi, the percentage of survivors living in temporary housing was the highest among the three municipalities (approximately 36.3%).[9 10] Many residents experienced a decrease in PA caused by sudden environmental changes. However, our previous study indicated that PA deterioration caused by the disaster was transitory, and several survivors improved their PA the year after the disaster.[11] Therefore, to assess the dynamic nature of PA in the disaster area, it should be assessed during both 2011 and 2012 rather than relying on a single baseline measurement.

Some longitudinal studies have reported an association between PA changes and all-cause mortality.[12–14] However, these studies have mainly focused on the general population rather than residents living in disaster areas. Therefore, it remains unclear whether PA changes are associated with an increased risk of all-cause mortality in disaster-affected areas. We hypothesised that decreased PA would be associated with elevated mortality rates among survivors after the GEJE. Particularly, there remains the possibility that the residents living in temporary housing have a higher risk of all-cause mortality because of changes in the environment. This study thus aimed to clarify the association between PA changes and the risk of all-cause mortality among GEJE survivors.

MATERIALS AND METHODS

Study participants

We analysed data from the Research Project for Prospective Investigation of Health Problems Among Survivors of the Great East Japan Earthquake and Tsunami Disaster (RIAS). Free health examinations were provided to all GEJE survivors aged ≥18 years who wished to participate in the health surveys between September 2011 and January 2012. The RIAS is a population-based longitudinal cohort study conducted over 10 years between 2011 and 2020. This study aimed to support the health of GEJE survivors. The areas surveyed in this study were Yamada Town, Otsuchi Town and Rikuzentakata City, which were heavily affected by the earthquake and the tsunami. In the initial survey in 2011, we sent out notifications of the health survey and questionnaires to all residents aged ≥18 years based on provisional figures compiled by municipalities. We asked residents to complete the questionnaire and bring it to their municipal check-up site. Annual survey in the RIAS consisted of self-reported questionnaires, anthropometric, clinical and physiological measures. If the answers to the questionnaire were inadequate, trained investigators verified the responses. After 2012, invitations were sent to individuals using the same method. Follow-up surveys were repeated annually using similar methods until the end of fiscal year 2020 (online supplemental addendum 1).[11 15]

Figure 1 shows a flowchart of the participant selection for this study. In this study, we used the 2012 survey as the baseline. Participants were residents aged ≥18 years living in the disaster area. In 2011, an invitation was sent to 42 286 community-dwelling residents. Overall, 10 203 participants provided written informed consent to participate in this study. The data analysed in this study spanned from 2012 to 2018.

Research ethics approval

This non-invasive, observational study complies with the Declaration of Helsinki. It was approved by the Institutional Review Board of Iwate Medical University (Approval No. H23-69; latest approval date: 31 January 2023). We informed participants of the potential risks and benefits of the study, and all participants provided their written informed consent.

Measurement

We obtained the variable for PA at two points (2011, 2012) and used other variables collected from the 2012 questionnaire.

Exposure: physical activity (PA) changes over 2 years after the Great East Japan Earthquake (GEJE)

For PA assessment, the questionnaire posed the following question: 'How long do you walk a day on average?' Participants were instructed to select one of the three options: ≤ 30 min, between 30 min and 1 hour, and ≥1 hour. Using a cut-off point of 30 min, we classified the participants into the 'low' and 'high' groups.[3 16] We

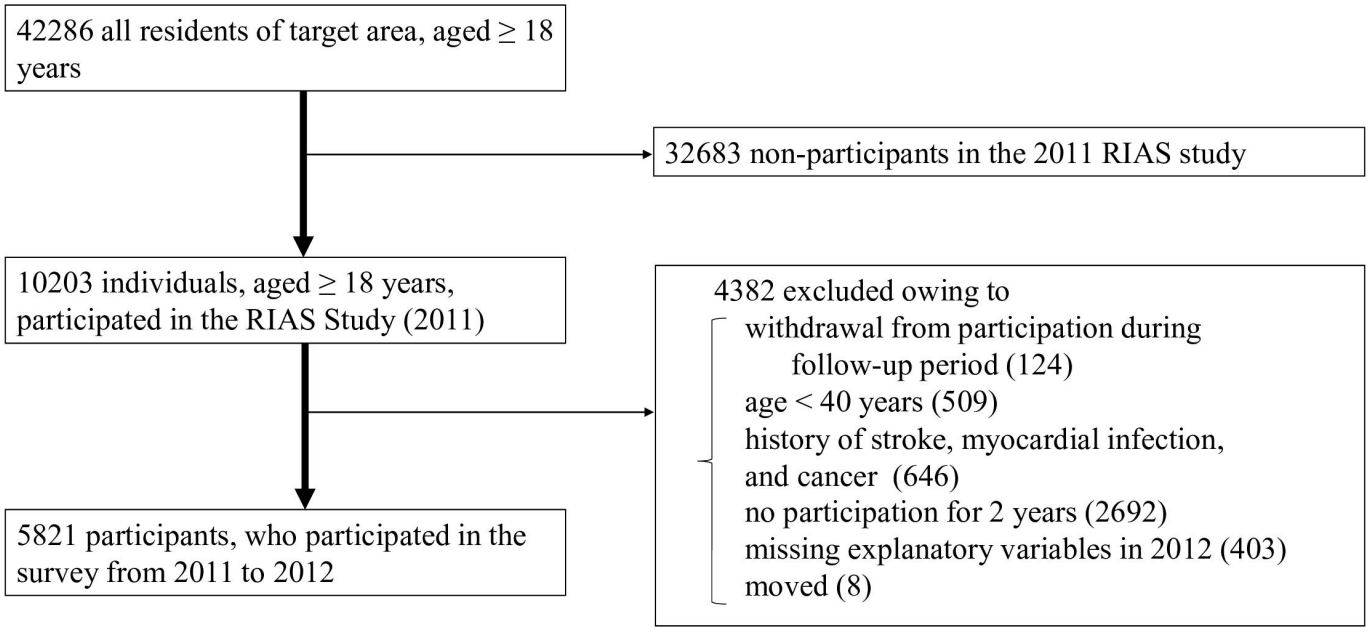

Figure 1 Flow diagram of the study participants in the present study. RIAS, Research Project for Prospective Investigation of Health Problems Among Survivors of the Great East Japan Earthquake and Tsunami Disaster.

reported that the survivors have experienced the most significant change in PA between 2011 and 2012 results of examining the changes in PA among survivors after the GEJE.[11] Therefore, walking times were assessed in 2011 and 2012. We classified the participants into the 'high stable', 'increasing', 'decreasing', and 'low stable' groups. In previous population-based prospective cohort studies, the validity of measuring PA with a single-item question was examined, and an association between walking time and walking steps or energy expenditure was reported.[17 18] Moreover, several studies have shown an association between walking time and health outcomes.[19–21]

Outcome: mortality ascertainment

All-cause mortality served as the primary outcome. Participants were followed up for 10 years from 2011, and information on deaths up to 31 March 2018 was registered by all municipalities. To identify cohort deaths, we examined transfer information. All deaths that occurred in the cohort, except for those who died after moving to their community, were treated as censored cases. Participants who moved out of the communities were also treated as censored cases.

Other covariates

Body mass index was calculated as the weight (kg) divided by the square of the height (m^2). Each patient was dichotomised into those with obesity (≥ 25.0 kg/m^2) and those without obesity (< 25.0 kg/m^2).[22 23] Blood pressure was consecutively measured twice in a sitting position using an automatic device after urination and a 5-min rest period, and the mean blood pressure was calculated. Hypertension was defined as undergoing treatment or blood pressure ≥140/90 mm Hg. Glycosylated haemoglobin (HbA1c) (Japan Diabetes Society (JDS) in 2011 and 2012 and National Glycohemoglobin Standardization Program (NGSP) in 2012) value was determined using an automated analyser. The HbA1c value (%) was estimated as the NGSP equivalent value (%), calculated using the following formula: HbA1c (NGSP) (%) = 1.02 (%) × HbA1c (JDS) (%) + 0.25 (%).[24] Diabetes mellitus was defined as undergoing treatment or HbA1c ≥6.5% (NGSP). Low-density lipoprotein (LDL) (mg/dL) and high-density lipoprotein (HDL) (mg/dl) levels were determined using an automated analyser. Dyslipidaemia was defined as undergoing treatment or LDL ≥140 mg/dL or HDL <40 mg/dL. A Smedley-type hand dynamometer was used to measure grip strength. Grip strength was measured twice for both the left and right hands of participants in a standing position using a dynamometer in kilograms. The participants held the dynamometer in a standing position and were encouraged to exert the strongest possible force. The maximum grip strength among all measurements was used in this analysis. If grip strength could not be measured owing to the dysfunction of one hand, it was measured using a non-dysfunctional hand. The cut-off value was set using the participant's median value based on sex (men, 39.0 kg; women, 26.0 kg). We recorded smoking status, drinking status, psychological distress, residential status and current job status based on self-reported responses in 2012. Smoking status was classified into two categories (never smokers vs former smokers or current smokers), and drinking status was similarly binarised (drinkers vs non-drinkers). Psychological distress was dichotomised into psychological distress (score of 10–24) and no psychological distress (score of 0–9) using Kessler's 6-item psychological scale (K6) score in Japan.[25] The K6 was used to assess

psychological distress,[26] and the Japanese version of the K6 was validated.[27] Using data from the 2012 survey, we classified residential status into two categories (none or temporary housing). In this study, 'prefabricated temporary housing', 'rental apartment', and 'shelter' were included in temporary housing. Regarding job status before and after the disaster, the following questions were asked: 'Did you work before the earthquake?' and 'Did you change your job status because of the earthquake?'. Subsequently, we classified the current job status into two categories: yes/no.

Statistical analyses

All analyses were separately performed for men and women because the distribution of lifestyle and psychological characteristics differed based on sex.

Cox proportional hazard models were used to estimate the association between PA changes and all-cause mortality. We investigated the risk of increasing, decreasing and low stability for all-cause mortality using high stability as the reference. A two-step process was used to determine the association between PA changes and all-cause mortality after adjusting for several factors associated with mortality. Model 1 included adjustments for age and town type, while model 2 (our main model) further included variables such as smoking status, drinking status, grip strength, psychological distress, obesity, hypertension, diabetes, dyslipidaemia, residential status and current job status using a multivariate-adjusted model. To clarify the effects of residential status, we performed a stratified analysis of the residential status in 2012.

The assumption of proportional hazard tested between changes in PA and all-cause mortality using Schoenfeld residual. Furthermore, a sensitivity analysis was performed to examine the influence of preclinical cases during the first 3 years of follow-up, excluding participants who died before 2014.

All P values were based on two-sided tests, and P values<0.05 were considered statistically significant. All analyses were performed using the IBM SPSS statistics V.25.0 (IBM Corp., Armonk, NY, USA).

Patient and public involvement

None.

RESULTS

During the average follow-up period of 5.3 years, 241 deaths (147 men and 94women) were identified.

We compared the baseline characteristics based on sex (online supplemental table S1). Compared with men, women were younger; were less frequent smokers or drinkers; had a lower prevalence of obesity, hypertension and diabetes; and were employed. However, they also exhibited a higher prevalence of dyslipidaemia and psychological distress.

Table 1 shows the baseline characteristics according to PA changes based on sex.

The low stable group had a higher proportion of psychological distress and temporary housing and a lower proportion of having jobs than did the other groups for both men and women. The increasing group had a higher proportion of smokers than did the other groups for men. The low stable group had a higher proportion of women with obesity than did the other groups. The youngest group was more likely to be in the decreasing group for men and the increasing group for women.

Table 2 shows the association between PA changes and all-cause mortality based on sex.

In the multivariate-adjusted model (model 2), both men and women in the decreasing group exhibited a significantly higher risk of all-cause mortality than that of those in the high stable group, with multivariate-adjusted HRs (95% CIs) of 2.40 (1.28 to 4.50) for men and 2.43 (1.04 to 5.72) for women. Among women, the low stable group had a significantly higher risk of all-cause mortality than that of the high stable group (2.76 (1.36 to 5.62)). However, among women, the increasing group was close to significance (1.51 (0.94 to 2.42)).

Sensitivity analyses, excluding participants who died within the first 3 years (41 men and 22 women), showed that men with an increasing group had a marginal but not significant inverse association at the point estimate with all-cause mortality; women had a higher association than in our main model with all-cause mortality, except for the low stable group (online supplemental table S2).

The subgroup analyses according to residential status are shown in table 3.

Among men not living in temporary housing, the decreasing group had a higher risk of all-cause mortality than that of the high stable group. Although no significant differences in the point estimate between PA changes and all-cause mortality were observed among men living in temporary housing, all three groups (increasing, decreasing and low stable groups) had a higher risk of all-cause mortality than that of the high stable group. However, among women not living in temporary housing, the decreasing group had a similarly higher risk of all-cause mortality compared with that of the high stable group. Significant differences in the association between PA changes and all-cause mortality were observed in the increasing and low stable group compared with that of the high stable group among women living in temporary housing. As with men, HRs similarly increased for those living in temporary housing compared with that of those who did not live in temporary housing for the three groups (increasing, decreasing and low stable groups). No significant interactions were found between residential status and PA changes regarding the association with all-cause mortality in either sex (interaction, p >0.05).

DISCUSSION

Our results demonstrated that both men and women participants with decreased PA had a significantly increased risk of all-cause mortality. Participants with

Table 1 Baseline characteristics of the participants according to physical activity (PA) changes based on sex (RIAS Study, 2012)

	PA changes				
	High stable	Increasing	Decreasing	Low stable	P value*
Men (n=2138)					
No. of participants	1582	405	73	78	
Age, mean (SD)	66.6 (10.5)	64.3 (11.7)	64.0 (11.5)	64.1 (12.7)	0.001
Area					
Yamada, %	34.1	27.2	57.5	26.9	
Otsuchi, %	20.2	14.6	23.3	32.1	
Rikuzentakata, %	45.8	58.3	19.2	41.0	<0.001
Smokers, %	62.1	71.4	63.0	65.4	0.007
Drinkers, %	64.5	64.4	63.0	65.4	0.992
Grip strength, <39.0 kg, %	48.1	44.2	45.2	50.0	0.507
Psychological distress, %	4.6	6.7	12.3	15.4	<0.001
Obesity, %	34.9	37.3	46.6	44.9	0.062
Hypertension, %	52.9	55.1	45.2	56.4	0.421
Diabetes mellitus, %	14.6	14.3	15.1	15.4	0.994
Dyslipidaemia, %	29.1	33.1	34.2	33.3	0.338
Temporary housing, %	28.4	37.0	39.7	46.2	<0.001
Current job, %	55.2	50.9	53.4	37.2	0.010
Women (n=3683)					
No. of participants	2538	913	103	129	
Age, mean (SD)	64.7 (10.4)	63.2 (11.4)	65.7 (10.9)	65.2 (12.7)	0.004
Area					
Yamada, %	32.2	25.0	39.8	32.6	
Otsuchi, %	20.4	16.0	34.0	33.3	
Rikuzentakata, %	47.4	59.0	26.2	34.1	<0.001
Smokers, %	7.1	7.8	7.8	9.3	0.724
Drinkers, %	12.5	14.3	14.6	11.6	0.494
Grip strength, <26.0 kg, %	47.8	46.7	54.4	54.3	0.222
Psychological distress, %	9.4	9.5	17.5	21.7	<0.001
Obesity, %	29.8	30.8	36.9	40.3	0.039
Hypertension, %	44.9	46.9	46.6	48.8	0.633
Diabetes mellitus, %	7.8	7.9	11.7	13.2	0.091
Dyslipidaemia, %	44.7	44.1	50.5	41.1	0.536
Temporary housing, %	28.0	32.3	40.8	45.7	<0.001
Current job, %	37.2	34.8	23.3	21.7	<0.001

*Obtained using analysis of variance for continuous variables and the χ^2 test for categorical variables, comparing among four groups of PA based on sex.
RIAS, Research Project for Prospective Investigation of Health Problems Among Survivors of the Great East Japan Earthquake and Tsunami Disaster; SD, Standard Deviation.

decreased PA in 2011 had a higher risk of all-cause mortality even if PA improved in 2012 compared with that of those who maintained PA over the 2 years (2011 and 2012). Furthermore, the participants in temporary housing had a higher risk of all-cause mortality than that of those not in temporary housing.

Several studies have investigated the association between PA changes and all-cause mortality among community residents.[14 28–30] Sanchez-Sanchez *et al* conducted a study on the association between PA trajectory and all-cause mortality using data from 1976 older persons in the Toledo Study of Healthy Aging. Compared with maintaining an increased baseline PA level, participants with low PA at baseline and a further decline in PA were associated with an increased risk of mortality.[31] A longitudinal study using data from 19 698 adults from the Copenhagen City Heart Study also revealed that decreased PA was associated with an increased risk of

Table 2 Association between physical activity (PA) changes and all-cause mortality based on sex in the RIAS Study

	PA changes (time spent walking from 2011 to 2012)			
	High stable	Increasing	Decreasing	Low stable
Men (n=2138)				
No. of participants	1582	405	73	78
Person-years	8421.7	2122.8	386.4	424.1
No. of deaths	104	26	11	6
Mortality rate (1000 person-years)	12.3	12.2	28.5	14.1
Model 1, HR (95% CI)	1.00 (Ref.)	1.22 (0.79–1.88)	2.56 (1.37–4.80)	1.22 (0.53–2.77)
Model 2, HR (95% CI)	1.00 (Ref.)	1.11 (0.72–1.72)	2.40 (1.28–4.50)	1.10 (0.48–2.55)
Women (n=3683)				
No. of participants	2538	913	103	129
Person-years	13664.6	4860.9	555.7	674.8
No. of deaths	52	26	6	10
Mortality rate (1000 person-years)	3.8	5.3	10.8	14.8
Model 1, HR (95% CI)	1.00 (Ref.)	1.53 (0.96–2.46)	2.35 (1.01–5.50)	2.76 (1.38–5.50)
Model 2, HR (95% CI)	1.00 (Ref.)	1.51 (0.94–2.42)	2.43 (1.04–5.72)	2.76 (1.36–5.62)

Model 1, adjusted for age and area. Model 2, model 1 +smoking status, drinking status, grip strength, psychological distress, obesity, hypertension, diabetes mellitus, dyslipidaemia, residential status and current job status.
RIAS, Research Project for Prospective Investigation of Health Problems Among Survivors of the Great East Japan Earthquake and Tsunami Disaster.

mortality.[32] Although a direct comparison is not appropriate because of the use of different survey and assessment methods and definitions of PA, our results align with previous findings on the association between PA changes and all-cause mortality.

Several possible explanations exist for the association between decreasing PA and all-cause mortality. First, the development of cardiovascular disease may increase the risk of all-cause mortality. Individuals with decreased PA have a significantly increased risk of developing myocardial infarction[32] and ischaemic stroke.[33] Decreased PA owing to environmental changes after a disaster may increase the incidence of cardiovascular diseases, resulting in an increased all-cause mortality rate among those with decreased PA. Second, the development of frailty may have contributed to all-cause mortality. Several studies have reported the association between frailty and mortality.[34–36] A previous study on the association between a 1-year PA change and frailty score using data from older individuals aged >70 years reported that participants with decreased PA and those with continued low PA were significantly more frail than were their counterparts.[37] A longitudinal study on the association between frailty and life-space constriction found that a slightly constricted life-space was associated with the development of frailty, whereas a severely constricted life-space might indicate a high risk of mortality.[38] In this study, a higher proportion of participants who experienced a decrease in PA lived in temporary housing than participants who never experienced a decrease in PA. Third, the decrease in PA and poor environment in the disaster area may have led to impaired immune function. Poor sanitary conditions often become a problem in temporary housing because of mildew.[39] The decline in the immune system owing to decreased PA and poor sanitary conditions may have contributed to the increased mortality risk. As we lack data on the causes of death, further investigation is required to specify the mechanisms underlying increased mortality owing to PA changes.

Contrary to our hypothesis, women with increasing PA had an increased risk of all-cause mortality, with a significant association after excluding women who died within the first 3 years. Although no significant interactions were found between residential status and PA changes, women in the low stable and increasing groups who lived in temporary housing had an increased risk of all-cause mortality. Among men, the sensitivity analysis revealed that the increasing group had an inverse association at the point estimate; those who improved their PA appeared to die earlier than did women. Some studies have shown the beneficial effects of increased PA on mortality risk, while others indicated an increased mortality risk despite PA improvement.[14 28–32] Sanchez-Sanchez *et al* have reported an association between PA and hospitalisation. They discussed that, particularly in older individuals, the effects of improved PA may be limited, even if their PA levels increase.[31] On the other hand, Petersen *et al* noted that the rates of cardiovascular disease among those who become more PA may be influenced by unadjusted lifestyle factors, and some individuals who have improved their PA might

Table 3 Association between physical activity (PA) changes and all-cause mortality based on sex according to residential status in the RIAS Study

	PA changes (time spent walking from 2011 to 2012)			
	High stable	Increasing	Decreasing	Low stable
Men				
Temporary housing (n=664)				
No. of participants	449	150	29	36
Person-years	2374.0	793.2	154.0	198.2
No. of deaths	21	9	3	3
Mortality rate (1000 person-years)	8.8	11.3	19.5	15.1
Model 1, HR (95% CI)	1.00 (Ref.)	1.59 (0.72–3.50)	2.78 (0.80–9.61)	1.58 (0.47–5.31)
Model 2, HR (95% CI)	1.00 (Ref.)	1.72 (0.74–4.02)	3.30 (0.89–12.20)	1.48 (0.42–5.17)
Not temporary housing (n=1474)				
No. of participants	1133	255	44	42
Person-years	6047.8	1329.6	232.4	225.9
No. of deaths	83	17	8	3
Mortality rate (1000 person-years)	13.7	12.8	34.4	13.3
Model 1, HR (95% CI)	1.00 (Ref.)	1.12 (0.66–1.90)	2.55 (1.22–5.30)	1.07 (0.34–3.41)
Model 2, HR (95% CI)	1.00 (Ref.)	1.00 (0.59–1.70)	2.28 (1.09–4.75)	0.96 (0.30–3.09)
Women				
Temporary housing (n=1106)				
No. of participants	710	295	42	59
Person-years	3784.8	1538.9	223.0	307.5
No. of deaths	12	12	1	6
Mortality rate (1000 person-years)	3.2	7.8	4.5	19.5
Model 1, HR (95% CI)	1.00 (Ref.)	3.00 (1.35–6.71)	1.78 (0.23–13.89)	3.20 (1.13–9.07)
Model 2, HR (95% CI)	1.00 (Ref.)	3.16 (1.38–7.25)	3.22 (0.40–26.22)	3.77 (1.31–10.85)
Not temporary housing (n=2577)				
No. of participants	1828	618	61	70
Person-years	9879.8	3322.0	332.8	367.3
No. of death	40	14	5	4
Mortality rate (1000 person-years)	4.0	4.2	15.0	10.9
Model 1, HR (95% CI)	1.00 (Ref.)	1.10 (0.60–2.02)	2.65 (1.04–6.76)	2.35 (0.84–6.61)
Model 2, HR (95% CI)	1.00 (Ref.)	1.04 (0.56–1.92)	2.65 (1.03–6.84)	2.42 (0.85–6.91)

Model 1, adjusted for age and area. Model 2, model 1 +smoking status, drinking status, grip strength, psychological distress, obesity, hypertension, diabetes mellitus, dyslipidaemia and current job status.
RIAS, Research Project for Prospective Investigation of Health Problems Among Survivors of the Great East Japan Earthquake and Tsunami Disaster.

adopt a physically active lifestyle to compensate for an adverse risk factor profile in order to prevent disease.[32] In our study, there is a possibility that the effects of increased walking time may have limited mortality risks for older individuals; conversely, they might develop a risk of cardiovascular disease as a result of increased walking time. The results of this study alone do not provide sufficient insight into why the risk of mortality increased among only women with improved PA, and this remains an area for future research. This study's results may be explained by the persistent effects of decreased PA after the disaster, which was associated with all-cause mortality despite PA subsequently improved. Particularly, living in temporary housing decreases PA owing to a lack of connection with local communities or changes in the environment.[40 41] Reportedly, participation in exercise classes or regular walking after a large natural disaster positively affects the health of the survivors.[42 43] A longitudinal study by Zhang *et al* on the effect of rehabilitation on survivors after the Sichuan Earthquake reported that providing rehabilitation to the survivors in hospitals or in the community after a disaster is effective in improving their activity daily living. Particularly, they showed that intervening at an earlier stage was more effective for the survivors

than that of those who received the intervention 1 year after the disaster.[44] It may be effective by the government and volunteers to promote participation for the survivors, particularly those who live in the temporary housing, in group exercises or community activities. Our findings indicate prioritising appropriating interventions as early as possible for survivors to prevent decreased PA.

This study has some limitations. First, we used walking time to measure PA. Assessing walking time may be useful because it provides a simple way to assess PA in survivors after a large natural disaster. However, previous studies have examined the association between PA and mortality using various assessment methods, such as metabolic equivalents and recreational activities.[14 28–30] Because walking time is strictly one of the assessments of PA, further studies need to be conducted to validate the multiple PA on associations between PA and mortality. Second, our study did not take into account changes in walking time after 2012. The present study focused on changes in PA in the 2 years after the GEJE because our previous study observed that dramatic PA changes were seen in these years among the 5 years after the GEJE.[11] It may be possible that PA might be changed drastically even after 2012 due to relocation and so on. Further study is required to clarify this point. Third, we could not determine the mechanism underlying the association between PA changes and mortality for several reasons. Reportedly, respiratory disease and cardiovascular disease were frequent causes of disaster-related death following the GEJE, and respiratory diseases accounted for half of the cases of death 1 year and after.[45] Furthermore, other study has reported that mental and physical fatigue from life at evacuation shelters was the most common cause of disaster-related death following the GEJE.[46] Thus, there is a possibility that PA was the cause of death among the survivors. However, in this study, we lacked data on the specific causes of death among the participants. Furthermore, although various factors, such as lifestyle changes, increase the risk of cardiovascular disease, diabetes and hypertension among survivors after a large disaster,[47 48] we lack information on all these factors. Fourth, the participants in this study were survivors who experienced lifestyle and environmental changes owing to the disaster. Therefore, attention should be paid when applying the results of this study to other disasters without relocation. Fifth, participants of our study may not be representative of the general population. There was a possibility that participants who lived in the areas with small damage might not recognise themselves as survivors. Furthermore, as this study was conducted during municipal health check-ups, individuals with high health consciousness were not willing to participate.[49 50] These factors could lead to an underestimation of our results. Sixth, we did not access effect of limited access to healthcare. It was possible that the survivors did not receive sufficient medical care after the GEJE because medical facilities and infrastructure were severely damaged by the disaster. Particularly, difficulty in accessing medical care services might be associated with mortality in those who lacked PA due to the disaster. Further studies are thus required to better understand the effects of environmental factors or social factors in the relationship between PA and mortality. Finally, the sample size of our study was not sufficient, particularly for decreasing group and low stable group. Thus, these results might not be robust. Further studies with a larger sample size is required.

Despite these limitations, the results of this study indicate the importance of assessing PA changes in survivors. Providing interventions based on PA changes in survivors may be crucial in decreasing the long-term risk of all-cause mortality.

In conclusion, PA changes after a large disaster are associated with all-cause mortality. Regardless of sex, those with decreased PA had an increased risk of all-cause mortality, and this association tended to be high even for participants with decreased PA in 2011 and those living in temporary housing. The results of this study indicate that PA changes should be assessed and highlight the importance of providing an environment in which PA can be maintained to prevent long-term mortality risk in disaster areas.

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