Title	Associations of cold spells and heat waves with frailty trajectory among older adults : a longitudinal study from the JAGES Study
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Title: Association of cold spell and heat wave with frailty trajectory among older adults: a longitudinal study from the JAGES Study

Abstract

Objectives: The impact of extreme weather on frailty trajectories in older adults remains unclear. This study explored the associations between cold spells/heat waves and frailty trajectories among this population.

Methods: A total of 6,582 older adults who completed four survey waves of the Japan Gerontological Evaluation Study (JAGES) in 2010, 2013, 2016, and 2019 were included. Frailty was assessed using the Kihon Checklist, and frailty trajectories were identified using group-based trajectory model. The cumulative number of days participants were exposed to cold spells and heat waves was calculated. Multinomial logistic regression models were applied to examine associations between extreme temperature exposure and frailty trajectories, with adjusted odds ratios (ORs) and 95% confidence intervals (CIs) estimated.

Results: Three frailty trajectories were extracted and labeled as frailty worsening, frailty maintenance, and frailty improvement. Of the 6,582 participants, 29.4%, 49.8% and 20.8% were subsequently classified into the above three trajectories. Every one-day increment of cold spell that participants suffered was associated with 5.4% (95% CI = 1.040-1.067) increased risk of frailty worsening after adjustment for covariables; similarly, each additional day of heat wave participants were exposed to, the risk of frailty maintenance and frailty worsening raised by 2.8% (95% CI = 1.004 - 1.028) and 4.5% (95% CI = 1.032 - 1.058), respectively.

Conclusions: Cold spells and heat waves are linked to higher frailty worsening risk in older adults, emphasizing the need for targeted public health interventions.

Key Words: heat wave; cold spell; frailty trajectory

Key messages:

What is already known on this topic

Previous studies have reported heat wave or ambient temperature was associated with raised risk of frailty or frailty progression in China, with little evidence on the long-term, cumulative effects on frailty trajectory in older adults, especially for those living in the super-aged society of Japan.

What this study adds

Utilizing the national cohort study for the Japanese old adults, the study finds prolonged and repeated exposure to cold spells and heat waves increase the risk of frailty worsening.

How this study might affect research, practice or policy

These findings suggest that public health interventions before and after extreme temperature events are encouraging to delay the frailty status worsening for the vulnerable old population.

Introduction

Frailty is an increasingly important public health concern in the context of global population aging.[1] It is a complex geriatric syndrome characterized by age-related declines in the resilience and functioning of multiple physiological systems, which render individuals more vulnerable to adverse health outcomes, including falls, disability, cognitive impairment, and mortality.[2] The prevalence of frailty increases with advancing age, with approximately 12% of community-dwelling older adults estimated to be frail.[3] Moreover, frailty is a dynamic condition, with transitions between robustness and frailty commonly observed. Previous studies have reported that 13.7% of older adults experience improvement in frailty status, 29.1% experience worsening, and 56.5% remain stable over time.[4] Given the complex and multifactorial nature of frailty, identifying determinants of distinct frailty trajectory groups is critical for the development of targeted and effective frailty prevention and management strategies.

A wide range of risk factors have been identified as being associated with the development of frailty, including nutritional status, lifestyle behaviors, social determinants, environmental exposures, and genetic factors.[5] Previous studies have shown that the absence of chronic conditions such as chronic obstructive pulmonary disease, diabetes, or stroke, along with never smoking and younger age, is associated with improvement in frailty status.[6] In addition, demographic characteristics (e.g., age and education level) and lifestyle factors, such as alcohol consumption, smoking status, and physical activity, have been reported to be closely associated with frailty trajectories among community-dwelling older adults.[7] Beyond age, recent studies have identified disability and a history of chronic diseases (e.g., diabetes and stroke) as significant determinants of frailty trajectories.[8,9] Global climate change is increasingly recognized as an important factor exacerbating challenges related to population aging. Many modifiable determinants of frailty—including lifestyle behaviors, disability, and morbidity among older adults—may be influenced by climate-related stressors, particularly extreme temperatures.[10] Previous studies have reported that exposure to heat waves[11] or low ambient temperatures during winter[12] was associated with an increased risk of frailty among older adults in China. More recently, evidence has also emerged linking ambient temperature exposure to frailty progression over time.[13] Meanwhile, accumulating evidence indicates that exposure to extreme temperatures (e.g., heat waves or cold spells) and temperature variability is associated with long-term adverse health outcomes in older adults, including cognitive decline, depressive symptoms, and cardiovascular disease.[14] Age-related chronic diseases and geriatric syndromes are more likely to reduce physiological reserve across multiple systems, thereby increasing vulnerability to adverse health events, including the development and progression of frailty. As a result, in the context of concurrent global population aging and climate change, ambient temperature may represent a critical yet underexplored risk factor influencing frailty trajectories. Most existing studies have primarily focused on the short-term (acute) health effects of extreme temperatures, such as immediate increases in mortality and cardiorespiratory events,[15 16] typically using daily exposure metrics and short time-series designs. In contrast, frailty is a gradually evolving condition that may be more strongly affected by long-term cumulative exposure to environmental stressors. We hypothesize that repeated exposure to extreme temperatures imposes sustained physiological stress on multiple organ systems, progressively eroding individual resilience and thereby influencing frailty trajectories over time. Therefore, this study aims to evaluate the long-term effects of cumulative exposure to cold spells and heat waves on frailty trajectories among older adults.

Methods

Participants

This prospective cohort study is from the Japan Gerontology Assessment Study (JAGES), an ongoing cohort study which recruited Japanese community-dwelling older adults aged 65 years or above since 1999, and the recruitment of cohorts expanded from two municipalities in Aichi Prefecture in 1999 to 30 municipalities in 14 prefectures in 2013. The old adults recruited were functionally independent, could take care of themselves and did not live in nursing homes. JAGES conducted the survey every three years by mailing self-administrated questionnaires to eligible older adults. The study protocol of JAGES is described elsewhere.[17]

The data adopted in this current study was from four waves of the surveys conducted in 2010, 2013, 2016, and 2019. The 2010 round survey was taken as the baseline survey and a total of 138,143 eligible older adults living in 31 municipalities in 12 prefectures were recruited. The mailed questionnaires were successfully collected from 78,866 participants, with response rate of 57.09%. Next, 18,409 (23.3%) participants who accomplished the Kihon Checklist (KCL) items, not have a mental disorder, missing covariates, and not frailty assessed using the KCL at baseline were selected.

Then, 6,582 (35.8%) participants who completed four-wave survey were selected for the further analysis (Figure 1). This study was reviewed and approved by the ethics committee of Chiba University (No. M10460). We obtained permission from the JAGES Data Administration Office to use the data from the JAGES investigators.

Frailty trajectories measurement

Frailty was assessed by the Kihon Check List (KCL, a basic function checklist in Japan),[18] which consists of 25 questions in the domains of physical, oral, social, and cognitive functions, nutritional status, and depressive mood (See Supplementary Table S1). The KCL is proved to be a reliable tool for predicting general frailty and frailty aspects in older adults,[19] and the KCL had validated in Japanese as a useful tool for frailty screening, with C-statistic being 0.81 for pre-frailty and 0.92 for frailty.[20] The description of several items or answer options in the KCI has been updated from survey to survey to describe it more accurately; the modification is shown in supplementary Text S1 and Table S2. The KCL score was calculated in light of the method shown in a previous study,[21] and it highlighted that the higher the KCL score, the more severe the frailty.

Then the frailty trajectory was generated with Group-based trajectory model (GBTM) via R software (Version 4.4.2) by using "Traj" package. The frailty trajectory was determined by starting with the model having one trajectory group and a cubic polynomial order, and repeated analysis was done by increasing the number of groups from 1 to 8 in the model. The optimal trajectory groups were determined by using standard deviation, mean of the first derivative, proportion of variance explained, mean of the second derivative, and clinical interpretability.[22] The model was then refined until the highest polynomial coefficient for each trajectory group was significantly different from zero.

Measurement of cold spells and heat waves

To capture long-term climatic conditions and account for the lagging effects of temperature on health, we defined extreme temperature thresholds using the daily mean temperature (℃) from the three years preceding each survey wave. Specifically, for the 2010, 2013, 2016, and 2019 waves, we collected the daily temperature data from 2007–2009, 2010–2012, 2013–2015, and 2016–2018, respectively. The daily mean temperatures from 2007 to 2018 recorded at 902 weather monitoring stations were obtained from the Japan Meteorological Agency, and all meteorological data underwent standard quality control procedures. In order to obtain spatially accurate and continuous temperature surfaces, we applied the inverse distance weighted (IDW) interpolation method to produce a 1 km × 1 km grid of daily temperatures across Japan. For each participant, daily temperature values were then extracted from the interpolated grid cell corresponding to their school district of residence. School districts were used as the spatial unit of exposure assessment in this study. In Japan, school districts represent meaningful community areas where older adults can typically travel on foot or by bicycle and are widely utilized in local public health planning.[23] According to the introduction from Japan Meteorological Agency, school districts generally cover an area of approximately 5–30 km^2. The population size varies according to municipal characteristics, typically ranging from around 2,000 to 8,000 residents. These features make school districts a practical and relevant spatial scale for characterizing community-level ambient temperature exposure among older Japanese adults. The previous studies also reported the low temperature variability over a range of tens of kilometers (approximately 20–50 km).[24] Consequently, The daily temperature across the 347 school districts covered within our final analytic sample made spatial variability available (see figure S1).

A heat wave was defined as a period of two or more consecutive days with a daily mean temperature above the school district-specific 95th percentile for that three-year duration. Similarly, a cold spell was defined as two or more consecutive days with temperatures below the school district-specific 5th percentile. These percentile-based, locally defined thresholds are commonly used in epidemiological studies to reflect local climatic conditions.[25-27] The two or more consecutive days were adopted because it has been shown to provide more stable statistical estimates.[28] Finally, for each participant, we calculated the total number of heat wave and cold spell days experienced within each of the four wave intervals, and used the sum of these days as the exposure variables.

Covariates assessment

The covariates were collected with self-administrated questionnaire, including age (year), gender, education years (<10, 10–12, or ≥13 years), body mass index (BMI [kg/m^2], calculated as the weight divided by the square of the height); marital status (married, other), equivalent income (low: < 2.0 million, middle: 2.0 - 4.0 million, high: ≥ 4.0 million [Japanese Yen]), smoking (No, Yes), alcohol drinking (No, Yes), living alone (No, Yes), self-rated health (poor, good), and chronic disease (hypertension, stroke, heart disease, diabetes, dyslipidemia, respiratory disease, musculoskeletal disease, and cancer). Chronic disease was then transformed as a single categorical variable (non, one, or two and more diseases) according to the number of the diseases suffered. Social activity which was defined as activities that require personal contact with other people in society. The social activity was assessed using a questionnaire comprising eight questions referring to eight types of social activity; three questions were slightly adjusted to reflect social developments during each survey (see Supplementary Table S3). For each type of social activity, every participant was asked to respond to the question of “How often do you participate in this type of activity?” and required to choose the most appropriate answer from a set of six options (never, a few times a year, once or twice a month, once a week, twice or thrice a week, almost every day). Then the value of 1, 2, 3, 4, 5, 6 were sequentially assigned to the six options mentioned above. The total score of social activity for each participant was calculated as the sum of scores from eight questions. The total score ranged from 8 to 48; the higher the score, the higher the level of participation in social activities.

Statistical analyses

The R software (version 4.2.2) was used for all analyses except for specifical statement. All tests were two-sided, and P value of less than 0.05 was considered as statistical significance. The continuous variables with normal distribution were displayed by mean and standard deviation (SD) and the distribution difference was examined by using one-way analysis of variance; the categorical variables were expressed by frequency and percentage and compared by generalized Cochran-Mantel-Haenszel Tests or chi-square test. The multinomial logistic regression model was used to examine the association of frailty trajectories with cold spell and heat wave, and the crude and adjusted odds ratio (OR) with 95% confidence interval (CI) were estimated. The multiplicative interaction of cold spell and heat wave was analyzed by using likelihood test that comparing the models with interactive term and without interactive term. Stratified analyses were done according to gender. A sensitivity analysis was done by excluding those aged more than 80 years, as they might suffered from a variety of age-related diseases or functional dependency.

Results

Three distinct frailty trajectories were identified and labeled as frailty worsening, frailty maintenance, and frailty improvement (see Figure 2). Among the 6,582 participants included in the analysis, 29.4% were classified into the frailty improvement trajectory, 49.8% into the frailty maintenance trajectory, and 20.8% into the frailty worsening trajectory (Table 1). The mean (SD) number of days participants experienced cold spells was 100.2 (1.2), with a range of 95 to 103 days, while the mean (SD) number of days participants experienced heat waves was 104.3 (1.2), ranging from 100 to 107 days. Compared with the other two trajectory groups, participants in the frailty worsening group were more likely to be male, married, have two or more chronic diseases, report poorer self-rated health, be nondrinkers, have middle-level equivalent income, engage in lower levels of social activity, be older, and have 10–12 years of education.

The association of cold spell and heat wave with frailty trajectories was shown in table 2. Every 1-day increment of cold spell that participants suffered was associated with 5.4% (95% CI = 1.040-1.067) increased risk of frailty worsening after adjustment for covariables; similarly, each additional day of heat wave participants were exposed to, the risk of frailty maintenance and frailty worsening raised by 1.6% (95% CI = 1.004 - 1.028) and 4.5% (95% CI = 1.032 – 1.058), respectively. However, no significant interaction was observed between cold spell and heat wave ($P > 0.05$).

In stratified analysis by gender, similar results were observed in both male and female (table 2); for males, every one-day increment of cold spell and heat wave was associated with 7.1% (95% CI = 1.049 - 1.094) and 4.0% (95% CI = 1.020 - 1.061) higher risk of frailty worsening; for female, every one-day increment of cold spell and heat wave was associated with 3.2% (95% CI = 1.011 - 1.054) and 1.9% (95% CI = 1.001 - 1.040) higher risk of frailty worsening.

In sensitivity analysis by excluding 130 participants aged more than 80 years (Table 3), consistent effect was observed that every 1-day increment of cold spell and heat wave was associated with 5.0% (95% CI = 1.034 - 1.067) and 2.1% (95% CI = 1.006 - 1.036) higher risk of frailty worsening.

Discussion

This study aimed to examine the long-term cumulative effects of heat waves and cold spells on frailty trajectories among older adults. We found that each one-day increase in cumulative exposure to cold spells and heat waves was associated with a higher risk of belonging to the frailty worsening trajectory. These associations remained consistent across stratified and sensitivity analyses, indicating the robustness of our findings.

In the context of global climate change, extreme temperatures are increasingly recognized as critical yet potentially modifiable threats to the multifaceted health of older populations. A growing body of evidence has documented both short-term and long-term effects of cold spells on frailty-related health outcomes, including cardiovascular disease,[29] circulatory and respiratory system diseases,[30] and cardiometabolic multimorbidity.[31] In recent years, studies from China have reported that lower ambient winter temperatures are associated with higher odds of frailty among older adults.[12] Another study further demonstrated that lower daily mean temperatures were negatively associated with frailty progression, defined as an increase of more than 0.1 in the frailty index score between two survey waves.[32] Building on this evidence, the present study leveraged a national cohort of older adults in Japan to investigate the long-term, cumulative effects of cold spells on frailty trajectories, characterized by patterns of change in frailty status across four survey waves. To our knowledge, this study is among the first to demonstrate that exposure to cold spells is associated with an increased risk of belonging to a frailty worsening trajectory. Experimental studies have shown that acute cold exposure can alter corticosterone levels and activate inflammatory pathways, which are linked to adverse health outcomes.[33] Extreme cold events also induce vasoconstriction of peripheral skin vessels to conserve body heat, leading to increased peripheral vascular resistance and cardiac workload.[34 35] In addition, cold spells may elevate the incidence of respiratory infections, such as influenza and pneumonia, and are associated with increased plasma cholesterol, plasma fibrinogen levels, and hypertension.[36] These physiological and pathological responses may further trigger or accelerate chronic disease progression and functional decline, which are central features of frailty.

Meanwhile, we also found that each one-day increase in cumulative heat-wave exposure was associated with a 4.5% higher risk of belonging to the frailty worsening trajectory among older Japanese adults. While the acute health effects of high temperatures have been extensively studied, our findings extend the existing literature by demonstrating a potential long-term impact of cumulative exposure to extreme heat on frailty progression. Unlike previous studies that primarily focused on short-term temperature anomalies and immediate health responses, our study captures sustained climatic stress accumulated over multiple years, which may gradually erode functional resilience in older adults. By examining frailty trajectories over a nine-year period, our analysis provides a more comprehensive perspective on the chronic health risks posed by climate change. Our results are consistent with recent evidence from China, which reported that exposure to heat waves was associated with a 4.8%–6.3% increased risk of frailty as defined by the frailty index.[11] Previous studies have also reported a non-linear association between the highest daily mean temperature and the risk of frailty progression, with an identified threshold of 31.8 °C.[32] Notably, older adults are particularly sensitive to heat waves due to age-related reductions in thermoregulatory capacity and the presence of comorbid conditions.[37] In addition, heat waves are often accompanied by accelerated photochemical reactions, leading to the formation of secondary air pollutants and changes in the concentration and composition of airborne contaminants.[38] Exposure to these pollutants may further increase the risk of frailty.[39] Prolonged and repeated exposure to extreme temperature events, such as cold spells and heat waves, may impose sustained physiological stress and impair the body's ability to maintain or restore homeostasis, thereby weakening physical resilience. Aging further attenuates thermoregulatory capacity and reduces resilience to thermal stress, increasing vulnerability during extreme temperature exposure. Our findings support the importance of public health interventions—such as enhanced social support and targeted protective measures—implemented before and after extreme temperature events to help delay frailty progression among vulnerable older populations.

This study has several strengths. First, because frailty is a dynamic process, we applied GBTM to identify distinct frailty trajectories, allowing for a more accurate characterization of longitudinal changes in health status among older adults. Second, we simultaneously assessed individual-level cumulative exposure to cold spells and heat waves, providing a more comprehensive evaluation of the effects of extreme temperatures on frailty trajectory patterns. Finally, the use of nationally representative data from the JAGES cohort enhances the generalizability of our findings and reduces biases commonly associated with smaller samples or cross-sectional study designs.

Nonetheless, several limitations should be acknowledged. First, our analysis included 6,582 participants who completed all four survey waves and met the inclusion criteria, representing approximately 8.4% of the baseline cohort. This restriction may raise concerns about potential selection bias. To address this, we compared the distributions of age and sex between participants who completed all four survey waves and those who did not. We find no statistical difference in the distribution of age and gender except for the age group of 65-69 years. These findings suggest that, with respect to these key demographic characteristics, the analytic sample is reasonably representative of the broader older adult population. Second, we applied a simple approach to measure cumulative exposure by summing all heat wave and cold spell days over the follow-up periods, which assumes that all past exposures contribute equally to frailty outcomes. Future analyses will apply a time-varying approach by segmenting the follow-up period according to survey waves and calculating exposure counts within each interval. Third, we did not account for other meteorological or environmental factors, including air pressure, wind speed, and air pollutants, which may interact with extreme temperatures to influence health outcomes.[11] These data were not available for the present analysis, but ongoing research will seek to incorporate these additional exposures. Fourth, our assessment of exposure to extreme temperature was based on ambient outdoor temperature rather than individual-level thermal exposure. Older adults with frailty may spend more time indoors, which could modify their actual heat or cold exposure. Future research should incorporate more detailed exposure assessment, including data on indoor housing characteristics, behavioral patterns, and social activity. Finally, frailty was assessed using the KCL. Although different versions of the KCL have demonstrated good applicability in population-based health research, this instrument may have limited ability to fully distinguish between frailty and disability. Nevertheless, functional decline and disability are core components of frailty. Therefore, using KCL to assess frailty is unlikely to have a significant effect on the results.

In conclusion, this study indicates that exposure to both cold spells and heat waves is associated with an increased risk of belonging to a frailty worsening trajectory among older adults. These findings underscore the need for targeted public health and policy interventions to mitigate or prevent the adverse impacts of extreme temperature events on vulnerable aging populations.

Abbreviations

CI: confidence interval; GBTM: Group-based trajectory model; IDW: inverse distance weighted; JAGES: Japan Gerontology Assessment Study; KCL: Kihon Check List; SD: standard deviation; OR: odds ratio.

Declaration

Source of funding and roles

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of this manuscript.

Conflicts of interest

The authors state that they have no conflicts of interest.

Ethics approval

This study was reviewed and approved by the ethics committee of Chiba University (No. M10460). We obtained permission (the JAGES Data Administration Office) to use the data from the JAGES investigators.

Consent to participants

This study was based on an established cohort dataset; Patients and/or the public were not involved in the design, conduct, reporting, or dissemination plans of this research.

Consent to publication

All co-authors provided comments and approved the final version.

Data availability statement

The data used to support the findings of this study are available from the corresponding author upon request.

Authorship contributions statement

xxx: Conceptualization, Methodology, Writing- Original draft preparation. **xxx:** temperature data collection, heat wave and cold spell days calculation. **xxx:** Writing-Reviewing and Editing. **xxx:** Project administration. **xxx:** Conceptualization, Methodology, Data Curation, Writing- Reviewing and Editing. **xxx:** Supervision, Reviewing and Editing.

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Figure legend

Figure 1. The flow chart of the participants

Figure 2. Trajectory groups of KCL score over time

The left figure shows the sample trajectory and the right figure shows the extracted three pointwise mean trajectories. Cluster 1 (grey color), cluster 2 (black color), and cluster 3 (red color) are labelled as frailty improvement, frailty maintenance, and frailty worsening in sequence.

Table 1. Basic characteristics of the participants in 2010 according to frailty trajectory groups

	Total	Frailty improvement	Frailty maintenance	Frailty worsening
Samples, n (%)	6,582	1,937	3,278	1,367
Age, years, mean (SD)	70.35 (3.93)	69.87 (3.68)	70.2 (3.78)	71.41 (4.4)
Body mass index, kg/m^2, mean (SD)	22.93 (2.78)	22.93 (2.65)	22.95 (2.82)	22.87 (2.89)
Cold spell, days, mean (SD)	100.24 (1.22)	100.23 (1.21)	100.23 (1.23)	100.3 (1.2)
Heat wave, days, mean (SD)	104.31 (1.21)	104.33 (1.19)	104.3 (1.22)	104.33 (1.2)
Social activity, score, mean (SD)	16.09 (6.65)	16.04 (6.49)	16.27 (6.69)	15.74 (6.8)
KCL score in 2010 survey, mean (SD)	2.86 (2.04)	2.68 (2.11)	2.76 (1.91)	3.36 (2.15)
KCL score in 2013 survey, mean (SD)	2.64 (2.28)	2.08 (1.84)	2.8 (2.36)	3.06 (2.47)
KCL score in 2016 survey, mean (SD)	2.61 (2.34)	1.81 (1.68)	2.67 (2.26)	3.61 (2.86)
KCL score in 2019 survey, mean (SD)	3.24 (2.86)	1.68 (1.66)	2.64 (1.85)	6.92 (3.08)
Gender, men, N (%)				
Men	3200 (48.6)	908 (46.9)	1571 (47.9)	721 (52.7)
women	3382 (51.4)	1029 (53.1)	1707 (52.1)	646 (47.3)
Education, N (%)				
< 10 years	1930 (29.3)	515 (26.6)	964 (29.4)	451 (33.0)
10–12 years	2904 (44.1)	900 (46.5)	1425 (43.5)	579 (42.4)
≥13 years	1748 (26.6)	522 (26.9)	889 (27.1)	337 (24.7)
Marital status, N (%)				
Married	5436 (82.6)	1625 (83.9)	2712 (82.7)	1099 (80.4)
Others	1146 (17.4)	312 (16.1)	566 (17.3)	268 (19.6)
Equivalent income, N (%)				
Low	1071 (16.3)	287 (14.8)	500 (15.3)	284 (20.8)
Middle	3047 (46.3)	874 (45.1)	1545 (47.1)	628 (45.9)
High	2464 (37.4)	776 (40.1)	1233 (37.6)	455 (33.3)
Employment status, N (%)				
Unemployed	4724 (71.8)	1382 (71.3)	2339 (71.4)	1003 (73.4)
Employed,	1858 (28.2)	555 (28.7)	939 (28.6)	364 (26.6)
Smoking, N (%)				
No	5976 (90.8)	1765 (91.1)	2955 (90.1)	1256 (91.9)
Yes	606 (9.2)	172 (8.9)	323 (9.9)	111 (8.1)
Alcohol drinking, yes, N (%)				
No	3472 (52.7)	980 (50.6)	1716 (52.3)	776 (56.8)
Yes	3110 (47.3)	957 (49.4)	1562 (47.7)	591 (43.2)
Living alone, N (%)				
No	5963 (90.6)	1766 (91.2)	2981 (90.9)	1216 (89.0)
Yes	619 (9.4)	171 (8.8)	297 (9.1)	151 (11.0)
Self-rated health, good, N (%)				
Poor	403 (6.1)	90 (4.6)	189 (5.8)	124 (9.1)
Good	6179 (93.9)	1847 (95.4)	3089 (94.2)	1243 (90.9)
Chronic diseases, N (%)				
None	3022 (45.9)	911 (47)	1539 (46.9)	572 (41.8)
One	2489 (37.8)	728 (37.6)	1224 (37.3)	537 (39.3)
Two or more, N (%)	1071 (16.3)	298 (15.4)	515 (15.7)	258 (18.9)

Abbreviation: KCL, Kihon Check List.

Table 2. Association of every one-day increment of cold spell and heat wave with the risk of frailty trajectory

	Cold Spell		Heat wave	
	Crude OR (95%CI)	Adjusted OR (95%CI)	Crude OR (95%CI)	Adjusted OR (95%CI)
Total				
Frailty improvement	1.000	1.000	1.000	1.000
Frailty maintenance	1.002 (1.002, 1.003)	1.003 (0.991, 1.015)	1.021 (1.020, 1.021)	1.016 (1.004, 1.028)
Frailty worsening	1.051 (1.051, 1.052)	1.054 (1.040, 1.067)	1.023 (1.023, 1.024)	1.045 (1.032, 1.058)
Male				
Frailty improvement	1.000	1.000	1.000	1.000
Frailty maintenance	1.006 (0.967, 1.048)	1.014 (0.996, 1.032)	0.992 (0.991, 0.992)	1.002 (0.985, 1.019)
Frailty worsening	1.055 (1.027, 1.085)	1.071 (1.049, 1.094)	1.007 (1.006, 1.008)	1.040 (1.020, 1.061)
Female				
Frailty improvement	1.000	1.000	1.000	1.000
Frailty maintenance	0.981 (0.98, 0.982)	0.983 (0.967, 1.000)	0.973 (0.972, 0.973)	0.970 (0.955, 1.001)
Frailty worsening	1.029 (1.028, 1.030)	1.032 (1.011, 1.054)	1.009 (1.009, 1.010)	1.019 (1.001, 1.040)

Adjusted OR was adjusted for age, gender, body mass index, smoking, alcohol drinking, married status, equivalent income, education, social activity, chronic disease, employment.

Table 3. Sensitivity analysis for the association of cold spell and heat wave with the risk of frailty trajectory after excluding the participants aged over 80 years

	Cold Spell		Heat wave	
	Crude OR (95%CI)	Adjusted OR (95%CI)	Crude OR (95%CI)	Adjusted OR (95%CI)
Frailty improvement	1.000	1.000	1.000	1.000
Frailty maintenance	0.994 (0.994, 0.995)	0.994 (0.981, 1.007)	0.978 (0.978, 0.979)	0.982 (0.970, 0.994)
Frailty worsening	1.047 (1.047, 1.048)	1.050 (1.034, 1.067)	1.001 (0.997, 0.998)	1.021 (1.006, 1.036)

Adjusted OR was adjusted for age, gender, body mass index, smoking, alcohol drinking, married status, equivalent income, education, social activity, chronic disease, employment.