

Preplanned Studies

Long-Term Temperature Variability and Risk of Dyslipidemia Among Middle-Aged and Elderly Adults: A Prospective Cohort Study — China, 2011–2018

Jianbo Jin¹; Yuxin Wang¹; Zhihu Xu¹; Ru Cao¹; Hanbin Zhang³; Qiang Zeng²;
Xiaochuan Pan¹; Jing Huang^{1,4,#}; Guoxing Li^{1,3,#}

Summary

What is already known about this topic?

Long-term temperature variability (TV) has been examined to be associated with cardiovascular disease (CVD). TV-related dyslipidemia helps us understand the mechanism of how climate change affects CVD.

What is added by this report?

Based on the China Health and Retirement Longitudinal Study (CHARLS) from 2011 to 2018, this study estimated the long-term effect of TV on dyslipidemia in middle-aged and elderly adults.

What are the implications for public health practice?

This study suggested that long-term TV may increase the risk of dyslipidemia. With the threat of climate change, these findings have great significance for making policies and adaptive strategies to reduce relevant risk of CVD.

Dyslipidemia is a vital risk factor for cardiovascular disease (CVD) and has increased considerably in recent years. Temperature was convinced to be a major climate factor that affected plasma lipid levels (1). In 2021, Kang et al. suggested long-term temperature variability (TV), an indicator of extreme temperatures, increased the risk of CVD; furthermore, dyslipidemia can modify the long-term TV-related risk of CVD (2). Lao et al. also found that the variation of dyslipidemia prevalence showed seasonal features in China (3). However, as an indicator of climate change, TV was rarely included in exploring its impacts on dyslipidemia. Therefore, we evaluated the long-term effect of TV on dyslipidemia in middle-aged and older adults based on the China Health and Retirement Longitudinal Study (CHARLS) from 2011 to 2018.

The study data were collected from 17,596 individual participants in 150 county-level units sampled from 450 communities in 125 cities among

28 provincial-level administrative divisions (PLADs) of China selecting by the multi-stage probability sampling method. We excluded 1,615 participants with dyslipidemia, 5,753 participants without dyslipidemia reports, and 609 participants for the lack of key covariate information. The final analysis sample included 9,619 individuals without dyslipidemia at baseline with key variables in 2011–2018 (Supplementary Figure S1, available in <http://weekly.chinacdc.cn/>). In CHARLS, all participants provided written informed consent.

This study defined the dependent variable as being diagnosed with dyslipidemia or not at baseline. Diagnosed dyslipidemia was defined as participants' self-reports of ever having been diagnosed with dyslipidemia by doctors. The daily meteorological information of all selected cities in the same period (2011–2018) was obtained from the China Meteorological Science Data Sharing Service Network. Nearest-neighbour interpolation was applied to estimate the daily data across the mainland of China at a spatial resolution of a regular grid of 10 km × 10 km (ten-fold cross validation: $R^2=0.95$; root mean square error=2.34 °C). We calculated the annual standard deviation (SD) of the daily average temperature as the TV index, and TV of the year before each survey was considered as the long-term TV exposure. TV data were assigned to each participant by their residential cities and survey year. Annual average concentrations of fine particles with a diameter $\leq 2.5 \mu\text{m}$ (PM_{2.5}) from 2011 to 2018 were calculated from a combination of satellite observations, chemical transport modeling, and ground-based monitoring ($R^2=0.81$; slope=0.90) (4). We assigned the annual average city-level PM_{2.5} concentration of the year before each survey to each participant.

Recorded demographic characteristics (age, sex) in CHARLS were included in covariates. We also collated three lifestyle covariates (smoking, alcohol drinking, social interactions) and three socioeconomic status

covariates (education attainment, residence, and household income per capita). Household income status was divided into binaries by average. Educational attainment was divided by whether junior school education was attained. Gross domestic product (GDP) at the city level was also collected from the National Bureau of Statistics and China's National Knowledge Infrastructure. By the Kunlun-Qinling-Huaihe line, the cities were divided into southern cities and northern cities. Environmental variables and dependent variables were time-varying for each survey, and other covariables were the values at baseline.

We assessed the association between long-term TV and the incidence of dyslipidemia using time-varying Cox proportional hazards model on a year-based time scale. We first evaluated the effects of TV on a continuous scale and reported the association with per 1 °C increase in TV. According to a previous study about long-term TV (2), TV was also divided into three categories (low<8.03 °C, medium=8.03–10.23 °C, high>10.23 °C), with the low TV as the reference group. We tested the statistical significance of the linear trend between each category of TV and dyslipidemia.

We fitted three models with different categories of covariates, and TV was included as a continuous variable or categorical variable in the models. Punitive spline regression (df=3) was used to analyse the exposure-response curve of TV and dyslipidemia. Furthermore, we evaluated the modification in the association between long-term TV and dyslipidemia, stratifying by age, sex, residency, household income status, education attainment, and geographical location.

Data arrangement, cleaning, and all statistical analyses were conducted using R (version 4.0.2, R Foundation for Statistical Computing, Vienna, Austria) with packages dplyr, survival, smoothHR, and

coxme. Statistical significance was defined as $P<0.05$, two sides. We included 9,619 participants without dyslipidemia and found 1,848 of them with dyslipidemia during the follow-up period. The median follow-up time was 4 years [interquartile range (IQR): 2–7 years]. In cities of CHARLS, the average annual TV between 2011 and 2018 ranged from 4.18 °C to 17.75 °C. Participants living with high TV were more likely to have higher education attainment, live in urban areas, smoke more, drink less, and have higher PM_{2.5} exposure and higher incidence of dyslipidemia (Supplementary Table S1, available in <http://weekly.chinacdc.cn/>).

We observed a positive association between dyslipidemia and long-term exposure to TV in three models (details about the models can be found in Table 1). In model 3, we observed 8.3% [95% confidence interval (CI): 4.2%–12.6%] increase in dyslipidemia for each 1 °C increase in TV (Table 1). Compared with low TV levels, the increase in medium and high TV levels was associated with 34.0% (95% CI: 15.6%–55.3%) and 57.9% (95% CI: 30.3%–91.3%) higher risks of dyslipidemia in a significant positive trend (Table 1). We also did a sensitivity analysis using the interval years of TV between surveys as long-term exposure and found that hazard ratio (HR) was 1.079 (95% CI: 1.036–1.123) (Table 1). Punitive spline regression with 3 degrees of freedom showed that exposure-response curve of long-term TV exposure and dyslipidemia was almost linear (Figure 1).

Marginal significant difference was found in the long-term TV-related risk between participants with low education attainment (HR: 1.093; 95% CI: 1.011–1.181) and high education attainment (HR: 1.084; 95% CI: 1.036–1.134) (Interaction P value=0.053) (Supplementary Table S2, available in <http://weekly.chinacdc.cn/>). No significant difference

TABLE 1. Cox regression models of TV and dyslipidemia among middle-aged and elderly adults, 2011–2018.

Models	TV per 1 °C increment [Hazard ratio (95%CI)]	TV levels [Hazard ratio (95%CI)]			P
		Low	Medium	High	
Model 1*	1.089 (1.071–1.107)	1.00 (Ref)	1.346 (1.167–1.553)	1.566 (1.301–1.885)	<0.001
Model 2†	1.093 (1.052–1.136)	1.00 (Ref)	1.340 (1.156–1.553)	1.579 (1.303–1.913)	<0.001
Model 3§	1.083 (1.042–1.126)	1.00 (Ref)	1.338 (1.153–1.553)	1.583 (1.303–1.924)	<0.001
Model 4¶	1.079 (1.036–1.123)	1.00 (Ref)	1.279 (1.106–1.478)	1.389 (1.148–1.681)	<0.001

Abbreviations: CI=confidence interval; PM_{2.5}=particulate matter of diameter ≤2.5 µm; TV=temperature variability.

* Crude model.

† Adjusted for model 1 criteria and age, sex, whether having lifestyle of smoking, drinking, annual average temperature, PM_{2.5}, GDP.

§ Adjusted for model 2 criteria and residency, household income per capita, educational attainment.

¶ Adjusted for model 3 criteria, using the interval years of TV between surveys as long-term exposure.

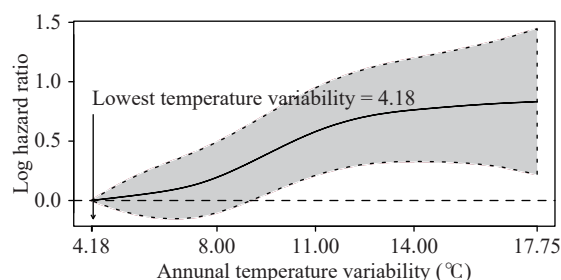


FIGURE 1. The exposure-response curve of long-term TV and dyslipidemia among middle-aged and elderly adults — China, 2011–2018.

Notes: Age, sex, marriage status, having disability, smoking, drinking, having accident injury, and having social interactions were adjusted. The solid line represents log hazard ratio, and the gray zone indicates 95% confidence interval.

Abbreviation: TV=temperature variability.

was found in the long-term TV effects in age, sex, residence, household income status, and living in different geographical regions.

DISCUSSION

In this study, we found a positive near-linear association between TV and risk the of dyslipidemia in middle-aged and elderly people. TV might affect the incidence of dyslipidemia, the risk factor of CVD.

Previous studies focused more on TV-related mortality or the incidence of CVD. A study analysed the effects of short-term TV among 31 cities in China, and observed a 1 °C rise of TV would increase 0.98 of CVD mortality (5). Shi et al. study in the USA found that for each 1 °C increase in TV, mortality in summer and winter increased by 0.80 and 0.41, respectively (6). A study in China with 35,000 participants over 35 years found that per 1 °C increase of long-term TV was associated with 6 increased incidence of CVD, and dyslipidemia was possibly a modifying factor (2). In this current study, we observed that higher TV would increase the incidence of dyslipidemia, which helps to understand the effects of long-term TV on CVD, especially among middle-aged and elderly populations. However, further studies were needed to examine the cause-and-effect relationship among long-term TV, dyslipidemia, and CVD.

Limited researches had been carried out to explore the underlying mechanism. Several studies suggested that extreme ambient temperature might affect the levels of high-density lipoprotein (HDL) and low-density lipoprotein (LDL), possibly by disturbing the absorbing of lipid (7–8). Some mechanistic studies

showed that the unstable temperature would affect other blood biomarkers, such as blood cholesterol levels and plasma fibrinogen concentrations (5). The fluctuation in ambient temperature due to climate change would result in an imbalance between energy intake and energy expenditure, which contributes to the prevalence of metabolic syndrome (9–10). The mechanism of how TV affects plasma lipid levels needs further investigation.

The study was subject to some limitations. First, because of the limitation of geographical information, exposure of TV was assessed at the city level, which might have induced exposure misclassification. Second, since the research object was the middle-aged and elderly people over 45 years old, the results could not represent the impact of long-term TV on dyslipidemia in younger people. Third, the long-term exposure could be affected by other potential unknown confounding factors, such as indoor air-conditioner use, which might have led to inaccurate estimation.

In conclusion, we observed that long-term exposure to TV may increase the risk of dyslipidemia. Under the challenges of climate change and aging of population, these findings provided implications for making policies and adaptive strategies, such as providing extreme temperature warnings and plans to protect people working outdoors. Further studies are needed to investigate the underlying mechanisms for the reported association.

Conflicts of interest: No conflicts of interest.

Acknowledgements: China Center for Economic Research, National School of Development, Peking University, Beijing, China.

Funding: Supported by from National Natural Science Foundation Project of China (81872590 and 41761144056).

doi: [10.46234/ccdcw2022.122](https://doi.org/10.46234/ccdcw2022.122)

Corresponding authors: Jing Huang, jing_huang@bjmu.edu.cn; Guoxing Li, liguoxing@bjmu.edu.cn.

¹ Department of Occupational and Environmental Health Sciences, Peking University School of Public Health, Beijing, China;

² Department of Occupational Disease Control and Prevention, Tianjin Centers for Disease Control and Prevention, Tianjin, China;

³ Environmental Research Group, MRC Centre for Environment and Health, Imperial College London, London, the United Kingdom;

⁴ Deep Medicine, Nuffield Department of Women's and Reproductive Health, University of Oxford, Oxford OX1 2BQ, the United Kingdom.

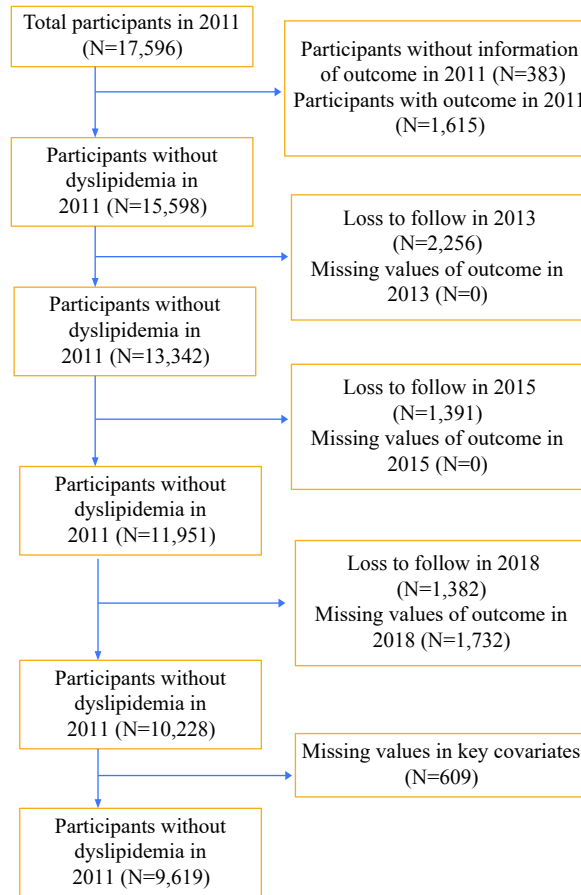
Submitted: December 17, 2021; Accepted: June 15, 2022

REFERENCES

1. Zhou XM, Lin HY, Zhang SG, Ren JW, Wang Z, Zhang Y, et al.

- Effects of climatic factors on plasma lipid levels: a 5-year longitudinal study in a large Chinese population. *J Clin Lipidol* 2016;10(5):1119 – 28. <http://dx.doi.org/10.1016/j.jacl.2016.06.009>.
2. Kang YT, Tang HS, Zhang LF, Wang S, Wang X, Chen Z, et al. Long-term temperature variability and the incidence of cardiovascular diseases: a large, representative cohort study in China. *Environ Pollut* 2021;278:116831. <http://dx.doi.org/10.1016/j.envpol.2021.116831>.
 3. Lao JH, Liu YF, Yang Y, Peng P, Ma FF, Ji S, et al. Time series decomposition into dyslipidemia prevalence among urban Chinese population: secular and seasonal trends. *Lipids Health Dis* 2021;20(1):114. <http://dx.doi.org/10.1186/s12944-021-01541-6>.
 4. Hammer MS, Van Donkelaar A, Li C, Lyapustin A, Sayer AM, Hsu NC, et al. Global estimates and long-term trends of fine particulate matter concentrations (1998-2018). *Environ Sci Technol* 2020;54(13):7879 – 90. <http://dx.doi.org/10.1021/acs.est.0c01764>.
 5. Yang J, Zhou MG, Li MM, Liu XB, Yin P, Sun QH, et al. Vulnerability to the impact of temperature variability on mortality in 31 major Chinese cities. *Environ Pollut* 2018;239:631 – 7. <http://dx.doi.org/10.1016/j.envpol.2018.04.090>.
 6. Shi LH, Liu PF, Wang Y, Zanobetti A, Kosheleva A, Koutrakis P, et al. Chronic effects of temperature on mortality in the Southeastern USA using satellite-based exposure metrics. *Sci Rep* 2016;6(1):30161. <http://dx.doi.org/10.1038/srep30161>.
 7. Halonen JI, Zanobetti A, Sparrow D, Vokonas PS, Schwartz J. Outdoor temperature is associated with serum HDL and LDL. *Environ Res* 2011;111(2):281 – 7. <http://dx.doi.org/10.1016/j.envres.2010.12.001>.
 8. Mathew AV, Yu J, Guo YH, Byun J, Chen YE, Wang L, et al. Effect of ambient fine particulate matter air pollution and colder outdoor temperatures on high-density lipoprotein function. *Am J Cardiol* 2018;122(4):565 – 70. <http://dx.doi.org/10.1016/j.amjcard.2018.04.061>.
 9. Turner JB, Kumar A, Koch CA. The effects of indoor and outdoor temperature on metabolic rate and adipose tissue – the Mississippi perspective on the obesity epidemic. *Rev Endocr Metab Disord* 2016;17(1):61 – 71. <http://dx.doi.org/10.1007/s11154-016-9358-z>.
 10. Wang TY, Zhou H, Sun QH. Fluctuation in ambient temperature: interplay between brown adipose tissue, metabolic health, and cardiovascular diseases. *Environ Dis* 2016;1(1):3 – 13. <http://dx.doi.org/10.4103/2468-5690.180334>.

SUPPLEMENTARY MATERIAL



SUPPLEMENTARY FIGURE S1. Flowchart of the study samples.

SUPPLEMENTARY TABLE S1. Comparison of the characteristics between included and excluded individuals among middle-aged and elderly adults — China, 2011–2018.

Characteristic	Excluded individuals (N=7,977)		Included individuals (N=9,619)		P
	No.	Percentage (%)	No.	Percentage (%)	
Age ≥65 (years)	2,440	30.59	2,315	24.07	<0.001
Male	3,959	49.63	4,470	46.47	<0.001
Smoking					<0.001
Current smoker	2,438	30.56	2,903	30.18	—
Former smoker	616	7.72	556	5.78	—
Never smoker	4,886	61.25	6,160	64.04	—
Drinking					0.330
Never drinker	4,668	58.52	5,675	59.00	—
Rare drinker	835	10.47	949	9.87	—
Regular drinker	2,431	30.48	2,995	31.14	—
Having social interactions					<0.001
Daily interactions	1,820	22.82	2,173	22.59	—
Weekly interactions	754	9.45	1,093	11.36	—
Occasional interactions	781	9.79	1,380	14.35	—
No interactions	3,124	39.16	4,973	51.70	—
Primary school and below	5,045	63.24	6,667	69.31	<0.001
Urban residency	3,864	48.44	3,233	33.61	<0.001
High household income	2,816	35.30	2,529	26.29	<0.001
Living in the south	4,134	51.82	5,259	54.67	<0.001
PM _{2.5} (µg/m ³), Mean±SD	49.94±23.08		51.29±23.31		<0.001
Air temperature (°C), Mean±SD	14.07±5.54		14.53±5.15		<0.001
Long-term TV (°C), Mean±SD	9.88±2.57		9.60±2.39		<0.001

Note: “—” means not applicable.

Abbreviations: PM_{2.5}=particulate matter of diameter ≤2.5 µm; SD=standard deviation; TV=temperature variability.

SUPPLEMENTARY TABLE S2. The association between long-term TV and dyslipidemia in stratified analyses — China, 2011–2018.

Characteristics	Subgroup	Hazard ratio (95% CI)	P value
Sex	Male	1.094 (1.030, 1.162)	Ref.
	Female	1.073 (1.019, 1.129)	0.453
Age	<65 years	1.079 (1.033, 1.127)	Ref.
	≥65 years	1.095 (1.004, 1.195)	0.978
Residency	Rural	1.092 (1.042, 1.145)	Ref.
	Urban	1.094 (1.017, 1.176)	0.324
Household income	Below average	1.086 (1.040, 1.134)	Ref.
	Above average	1.080 (0.984, 1.185)	0.579
Education attainment	Primary school and below	1.093 (1.011, 1.181)	Ref.
	Junior school and above	1.084 (1.036, 1.134)	0.053
Region	Living in northern cities	1.078 (1.016, 1.145)	Ref.
	Living in southern cities	1.087 (1.017, 1.163)	0.312

Notes: Model 3 adjustment (as illustrated in the Table 1 footnote) was used for the stratified analyses.

Abbreviations: TV=temperature variability; CI=confidence interval; Ref.=reference.