The Effect of Temperature on Mental Health: Evidence from China

Meng Wang and Cheng Huang(✉)

Harbin Institute of Technology, Shenzhen, China
wangmeng_joy@163.com

Abstract. The health impact of climate change has become an important public health issue. This paper examines the effects of extreme temperature on mental health status, using a nationally representative survey data from China Family Panel Studies (CFPS) database. This analysis finds that exposure to heat waves would increase the levels and frequency of depression, while the effects of cold temperatures are not obvious. Moreover, female, the middle-aged population, and people with lower education levels are more susceptible and suffer more when exposed to high temperature. Based on the local temperature and climatic adaptation, we also find a significant impact of large temperature deviation on the population. Our results suggest that mental health impacts of temperature and temperature variability potentially affect a significant part of the population.

Keywords: Temperature · Mental health · Climate change

1 Introduction

Since the industrial age, fossil fuels have led to massive greenhouse gas emissions, resulting in a sharp rise in average temperatures and climatic events, such as extreme temperature, precipitation, and hurricanes [1]. Climate change is proceeding at a fast rate than ever before, and it is estimated that the global ambient temperature will increase by 0.3 ~ 0.7 °C per year in the next 30 years [2]. As shown in Fig. 1, the 2020 Bulletin on The State of China's Ecological Environment also shows that the annual average of national temperature has been rising year by year since 1951, given the impact of global climate change, and the temperature varies greatly among different regions. The impact of abnormal temperature to human being health has been recognized as one of the most crucial issues and has obtained mass attention from global research [3]. Extreme temperature significantly threatens physical health. Some pieces of literature have probed the influential role of temperature on mortality and morbidity, and extreme temperature leads to a significant decline in health status by inducing cardiovascular, cerebrovascular, and respiratory diseases [4–6].

Additionally, extreme temperature also pose mental health challenges, with a large number of research pointing to links between mental health and meteorological factors. With the occurrence of temperature extremes, reports of poor mental health [7], negative

G. Ali et al. (Eds.): ISEMSS 2022, ASSEHR 687, pp. 478–488, 2022.
https://doi.org/10.2991/978-2-494069-31-2_60

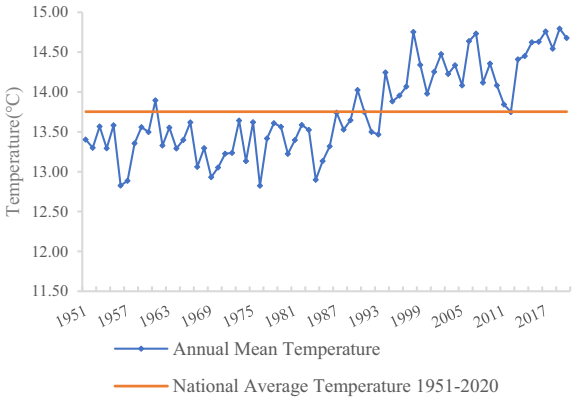

Fig. 1. Interannual variation of national mean temperature from 1951 to 2020 in China. Source: The China Meteorological Data Service Center.

emotions [8, 9] and suicide [10] increased. A comprehensive understanding of the relation between temperature and mental health is important to explore the social burden of poor mental health and effectively propose an approach to tackle climate change in the future.

Literature in extensive epidemiology and public health analyses the effects of temperature extremes on human health using a Poisson regression framework. However, the results reported in these studies might be confused with "harvest" or delayed effects on account of the short exposure window. On the contrary, researches on the health effects of climate change in economics have typically modeled temperature through temperature bins in order to explain the nonlinearity of the temperature-health outcomes relationship.

We follow the temperature-bins approach in several pieces of literature [4, 11], to investigate the mental health effects of extreme temperature on the Chinese population. Our study was based on mental health indicators in the CFPS survey and daily weather variables from the China National Meteorological Data Service Center (CMDC). We modeled temperature distributions from certain bins, and controlled for various weather variables, consisting of precipitation, humidity, and sunshine duration. Furthermore, we conducted some heterogeneous analyses to explore whether the relationships between subgroups and temperature extremes are different.

The paper proceeds as follows. Section 2 presents the data sources and the empirical methodology. Section 3 provides our baseline and heterogeneous results. Section 4 concludes the paper.

2 Data and Empirical Strategy

2.1 Data

The data set for our analysis is based on several sources. The mental health data comes from the China Family Panel Studies (CFPS) database, which is conducted by the Institute of Social Science Survey of Peking University. Since 2010, CFPS has conducted

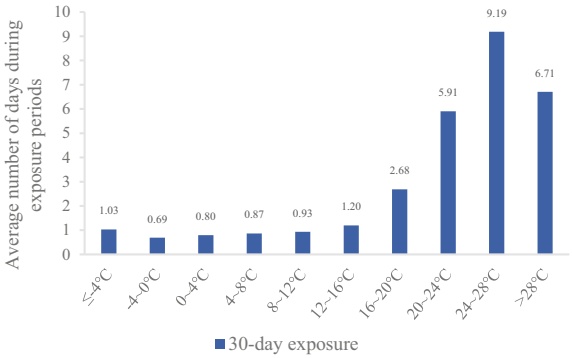

Fig. 2. Distribution of daily mean temperature during different exposure periods. Source: Author's calculation using data from CMDC.

surveys every two years among over 100,000 residents in 162 counties in 25 provincial regions. As CFPS is a nationally representative survey, it covers a lot of comprehensive individual health variables, and identifies the county and date of residents' interviews, providing access to match environmental time-varying information. In our study, we choose to use the dataset of CFPS 2012, 2016, and 2018 surveys because the same module to evaluate mental health status, CES-D (Center for Epidemiologic Studies Depression), is conducted in these surveys. The CES-D scores are used to indicate the degree of depression, the higher the score, the stronger the depression. Also, we use the frequency of respondents' depression to measure short-term depressive status related to immediate weather status. In particular, 1, 2, 3 and 4 are assigned to represent "almost none (less than a day)", "sometimes (1–2 days)", "often (3–4 days)", and "most of the time (5–7 days)", respectively.

The China National Meteorological Data Service Center (CMDC) provides the daily temperature data and other weather indicators from 825 weather stations in China. The county-level weather data are constructed by taking an inverse-distance weighted (IDW) average of all the weather indicators from stations located within a 60-km radius of the centroid of each county is calculated. If a county has no weather station within 60 km, the county would be matched with the nearest station within 100 km.

We match the CFPS dataset with the daily weather indicators via the specific interview day and county where each respondent resides. To be specific, ten temperature bins are constructed in our analysis, including ≤ -4 °C, −4–0 °C, 0–4 °C, 4–8 °C, 8–12 °C, 12–16 °C, 16–20 °C, 20–24 °C, 24–28 °C, and > 28 °C. Figure 2 depicts the temperature bins distribution of daily mean temperature during the 30-day period, that all observations are exposed to. The average number of days, that individuals in the survey is exposed in each temperature bin, is represented by the vertical axis.

2.2 Empirical Strategy

We apply an econometric approach to estimate the effect of temperature on elderly health, the baseline model is as follows:

$$Y_{icdy} = \sum_{1}^{10} \alpha_j TEMP_{cdyj} + \beta\omega_{cdy} + \phi\chi_{icdy} + \eta_i + \delta_c + \gamma_y + \sigma_d + \in_{icdy} \quad (1)$$

where the dependent variable Y_{icdy} denotes the mental health status of respondent i in county c on month d of year y. The key variable $TEMP_{cdyj}$ is the number of days in the j th temperature bin (from 1 to 10), which are illustrated in Sect. 2.1, during 30-day exposure for individual i interviewed in month d of year y in county c, and we set the 12–16 °C temperature bin as the reference group. In this way, the coefficient of $TEMP_{cdyj}$ indicates the effects of an additional day in the j th bin on the mental health status compared with the reference group. Abundant weather indicators ω_{cdy} are also considered as the control variables in the analysis. χ_{icdy} represents a set of individual demographic indicators, η_i denotes individual fixed effects. δ_c, γ_y and σ_d are county fixed effects, year fixed effects and month fixed effect. $\in_{icdy}$ is the error term. The standard errors are clustered at the county level.

3 Results

3.1 Basic Results

Table 1 reports the estimation of Eq. (1). We exercise by regressing the temperature bins variables on the two mental health variables without controlling for relative weather indicators and several health behaviours. The reference group is the 12–16 °C bin. As shown in column (3), when the temperature is below 12 °C, CES-D20 scores increase as temperature decreases except in the extreme cold bin. The temperature below −4 °C would decrease CES-D20 scores and ease depression to some degree. However, for the frequency of depression, the lower temperature seems to have no significant impact on it. When temperature is above 16 °C, both CES-D scores and frequency of depression increase gradually, which means higher temperatures make the mental health status worse. For instance, one additional day of temperature above 28 °C would increase the CES-D20 score and the depression frequency by 8.7% and 0.7%, respectively.

3.2 Results by Age Group

We examine the temperature impacts on CES-D20 scores and frequency of depression, for different age groups. As shown in Table 2, exposure to high temperatures do harm mental health significantly, especially for people ages over 45. One additional day in the range of > 28 °C would cause an increase of 12.7% and 15.2% in CES-D20 scores for people ages 45–64, and over 65, respectively. Nevertheless, as for frequency of depression, the higher temperature only has a statistically significant impact on people ages 45–64.

Table 1. Temperature effect on mental health: Basic results.

	CES-D20 SCORES			**FREQUENCY OF DEPRESSION**		
	(1)	(2)	(3)	(4)	(5)	(6)
TEMP ≤ −4 °C	−0.084*** (−3.66)	−0.091*** (−3.91)	−0.056*** (−3.23)	−0.002 (−1.32)	−0.003 (−1.55)	−0.003 (−1.56)
TEMP = −4–0 °C	0.015 (0.50)	0.005 (0.17)	0.030 (1.30)	0.003 (1.06)	0.002 (0.83)	0.002 (0.81)
TEMP = 0–4 °C	0.009 (0.26)	0.005 (0.14)	−0.010 (−0.39)	0.000 (0.14)	0.000 (0.09)	0.000 (0.07)
TEMP = 4–8 °C	−0.002 (−0.09)	−0.006 (−0.23)	0.055*** (2.66)	0.003 (1.17)	0.002 (1.08)	0.002 (1.08)
TEMP = 8–12 °C	0.021 (0.62)	0.020 (0.59)	0.045* (1.80)	0.005* (1.67)	0.004 (1.63)	0.004 (1.61)
TEMP = 16–20 °C	0.083*** (3.05)	0.086*** (3.16)	0.096*** (4.75)	0.008*** (3.71)	0.008*** (3.80)	0.008*** (3.79)
TEMP = 20–24 °C	0.035 (1.64)	0.039* (1.83)	0.043*** (2.74)	0.004** (2.04)	0.004** (2.28)	0.004** (2.27)
TEMP = 24–28 °C	0.091*** (3.73)	0.094*** (3.84)	0.079*** (4.31)	0.008*** (3.82)	0.008*** (3.94)	0.008*** (3.93)
TEMP > 28 °C	0.073*** (2.68)	0.085*** (2.94)	0.087*** (4.07)	0.006*** (2.80)	0.007*** (3.05)	0.007*** (3.04)
WEATHER CONTROLS	×	✓	✓	×	✓	✓
GENDER	✓	✓	✓	✓	✓	✓
AGE	✓	✓	✓	✓	✓	✓
AGE*AGE	✓	✓	✓	✓	✓	✓
URBAN	✓	✓	✓	✓	✓	✓
MARRIAGE	✓	✓	✓	✓	✓	✓
EDUCATION	✓	✓	✓	✓	✓	✓
HOUSEHOLD PER CAPITA INCOME	✓	✓	✓	✓	✓	✓
SMOKE	×	×	✓	×	×	✓
DRINK	×	×	✓	×	×	✓
MONTH FIXED EFFECT	✓	✓	✓	✓	✓	✓

(*continued*)

Table 1. (*continued*)

	CES-D20 SCORES			FREQUENCY OF DEPRESSION		
	(1)	(2)	(3)	(4)	(5)	(6)
YEAR FIXED EFFECT	✓	✓	✓	✓	✓	✓
COUNTY FIXED EFFECT	✓	✓	✓	✓	✓	✓
OBSERVATION	78219	78219	76306	76237	76237	76233

t statistics in parentheses.
***p < 0.01, **p < 0.05, *p < 0.1.

3.3 Results by Gender

Considering the gender difference, we test the effect of temperature on mental health status of female and male separately, based on Eq. (1). Generally speaking, female is vulnerable to extreme temperature because of their physical structure, hormone levels, and social pressure. As shown in column (1) and (3), when temperature is above 16 °C, the effects on both CES-D20 scores and frequency of depression for females would increase significantly. In particular, the heat-related effect for females becomes larger as temperature increases. Similar results were found in male group, but two ranges of high temperature do not statistically significantly affect the mental health status of males (Table 3).

3.4 Results by Educational Attainment

To identify the heterogeneous effects of temperature on mental health by educational attainment, we repeat the exercise by junior high school or below and senior high school or above. Table 4 reports the estimation coefficients on each temperature bin. When temperature is below −4 °C, both two dependent variables decrease. High temperature increases the psychological burden for all groups, and the effect on people with primary school education or below is especially obvious. One additional day with temperature above 28 °C would result in an increase of 18.7% in CES-D20 scores for people with six years of education or below.

3.5 Estimation of Temperature Deviation

Because local temperature patterns might have continuous impacts on residents, and climatic adaptation has been extensively explored in the literature as well [12], we report the results using temperature deviation in Table 5. We calculate the county-level average and standard deviation of daily mean temperature in the following-up period, and we subtract the 30-day daily temperature from the average temperature for each observation,

Table 2. Temperature effect on mental health: Estimation by age group.

	CES-D20 scores					**Frequency of Depression**			
	Age 0–18	Age 19–44	Age 45–64	Age 65 +		Age 0–18	Age 19–44	Age 45–64	Age 65 +
TEMP ≤ −4 °C	0.254 (1.19)	−0.070*** (−2.64)	−0.049* (−1.65)	−0.006 (−0.10)		0.003 (0.12)	−0.004 (−1.46)	0.004 (1.17)	−0.005 (−0.70)
TEMP = −4–0 °C	0.006 (0.02)	0.015 (0.42)	0.036 (0.87)	0.057 (0.65)		−0.029 (−0.70)	−0.002 (−0.52)	0.007 (1.53)	0.003 (0.28)
TEMP = 0–4 °C	0.704** (2.57)	−0.072** (−1.97)	0.024 (0.53)	0.077 (0.81)		0.045 (1.29)	−0.004 (−0.93)	0.009* (1.80)	−0.000 (−0.02)
TEMP = 4–8 °C	−0.003 (−0.02)	0.070** (2.31)	0.040 (1.06)	0.095 (1.17)		−0.034 (−1.16)	0.003 (1.03)	0.004 (0.96)	0.001 (0.07)
TEMP = 8–12 °C	0.315 (1.39)	−0.001 (−0.03)	0.073 (1.61)	0.074 (0.72)		−0.010 (−0.33)	−0.002 (−0.52)	0.014*** (2.66)	0.005 (0.43)
TEMP = 16–20 °C	0.164 (0.79)	0.032 (1.04)	0.141*** (4.02)	0.133* (1.90)		−0.014 (−0.55)	0.003 (0.85)	0.016*** (4.15)	0.005 (0.72)
TEMP = 20–24 °C	0.007 (0.04)	−0.036 (−1.47)	0.081*** (2.94)	0.122** (2.21)		−0.005 (−0.24)	−0.003 (−0.95)	0.009*** (2.78)	0.010* (1.67)
TEMP = 24–28 °C	0.204 (1.16)	0.019 (0.67)	0.115*** (3.59)	0.139** (2.24)		0.012 (0.55)	0.002 (0.66)	0.013*** (3.57)	0.010 (1.56)
TEMP > 28 °C	0.043 (0.20)	−0.002 (−0.05)	0.127*** (3.45)	0.152** (2.12)		−0.007 (−0.26)	0.001 (0.19)	0.011*** (2.73)	0.013 (1.64)
Observation	3132	28841	31497	12836		3131	28827	31477	12798

Note: All regressions include controls for other weather indicators, demographic information, and year, month and county fixed effect
***p < 0.01, **p < 0.05, *p < 0.1.

Table 3. Temperature effect on mental health: Estimation by gender.

	CES-D20 scores			**Frequency of Depression**	
	Female	Male		Female	Male
TEMP ≤ −4 °C	−0.064** (−2.46)	−0.049** (−2.13)		−0.003 (−1.05)	−0.003 (−1.22)
TEMP = −4–0 °C	0.053 (1.50)	0.005 (0.15)		0.002 (0.51)	0.001 (0.41)
TEMP = 0–4 °C	−0.018 (−0.46)	−0.003 (−0.09)		0.003 (0.63)	−0.002 (-0.51)
TEMP = 4–8 °C	0.053* (1.67)	0.057** (2.08)		0.003 (0.86)	0.002 (0.53)
TEMP = 8–12 °C	0.050 (1.33)	0.041 (1.23)		0.004 (0.97)	0.005 (1.29)
TEMP = 16–20 °C	0.123*** (4.14)	0.069** (2.51)		0.010*** (3.19)	0.006** (2.09)
TEMP = 20–24 °C	0.080*** (3.39)	0.007 (0.34)		0.007** (2.55)	0.001 (0.52)
TEMP = 24–28 °C	0.118*** (4.33)	0.040* (1.65)		0.011*** (3.55)	0.005* (1.91)
TEMP > 28 °C	0.129*** (4.07)	0.044 (1.55)		0.010*** (2.89)	0.004 (1.29)
Observation	38612	37694		38569	37664

Note: All regressions include controls for other weather indicators, demographic information, and year, month and county fixed effect
***p < 0.01, **p < 0.05, *p < 0.1.

and then divided by standard deviation. Finally, we model daily temperature variation by standard deviation using nine bins. Table 5 represents the results, showing that both temperatures decrease and increase between three and four standard deviations would increases CES-D20 scores and frequency of depression largely.

4 Conclusion

In our study, we investigate the effects of exposure to extreme temperature on the mental health status of all-age population, including CES-D20 scores and frequency of depression. Our results report that exposure to extreme cold might not influence the frequency of depression, but would increase the depression scores. However, exposure to hot or extreme hot temperature would have significant impacts on the two mental health indicators. Besides, we find that female, middle-aged population and people with deficient educational attainment are more vulnerable to the heat waves. Considering the climatic adaptation and temperature deviation, we find that dramatic temperature deviation would induce an increase in depression.

Table 4. Temperature effect on mental health: Estimation by educational attainment.

	CES-D20 scores			**Frequency of Depression**	
	Primary school or lower (< = 6 years)	Junior high school or above (> 6 years)		Primary school or lower (< = 6 years)	Junior high school or above (> 6 years)
TEMP ≤ −4 °C	−0.067** (−2.19)	−0.046** (−2.21)		−0.007** (−2.08)	−0.001 (−0.48)
TEMP = −4–0 °C	0.075* (1.78)	0.017 (0.60)		0.006 (1.20)	0.001 (0.38)
TEMP = 0–4 °C	−0.015 (−0.34)	0.011 (0.37)		−0.000 (−0.09)	0.001 (0.30)
TEMP = 4–8 °C	0.104*** (2.85)	−0.002 (−0.10)		0.004 (1.03)	−0.001 (−0.35)
TEMP = 8–12 °C	0.068 (1.43)	0.045 (1.58)		0.003 (0.61)	0.006* (1.93)
TEMP = 16–20 °C	0.167*** (4.81)	0.046* (1.85)		0.012*** (3.09)	0.006** (2.11)
TEMP = 20–24 °C	0.104*** (3.69)	0.014 (0.76)		0.008** (2.53)	0.002 (0.99)
TEMP = 24–28 °C	0.170*** (5.26)	0.018 (0.84)		0.014*** (3.99)	0.004 (1.52)
TEMP > 28 °C	0.186*** (4.93)	0.026 (1.02)		0.014*** (3.43)	0.003 (1.04)
Observation	34099	45374		34036	45363

Note: All regressions include controls for other weather indicators, demographic information, and year, month and county fixed effect
***p < 0.01, **p < 0.05, *p < 0.1.

Table 5. Temperature effect on mental health: Temperature variation related to local average and standard deviation.

	CES-D20 scores			**Frequency of Depression**	
	(1)	(2)		(3)	(4)
(temp-avetemp)/sd(temp)					
≤ −4	−0.225 (−0.27)	−0.179 (−0.21)		−0.044 (−0.48)	−0.041 (−0.45)
−4 ~ −3	0.432** (2.38)	0.433** (2.39)		0.050** (2.54)	0.051*** (2.58)
−3 ~ −2	0.021 (0.56)	0.024 (0.62)		−0.001 (−0.22)	−0.001 (−0.13)
−2 ~ −1	−0.023 (−1.58)			−0.002 (−1.29)	
1 ~ 2	0.007 (0.69)			−0.000 (−0.29)	
2 ~ 3	−0.021 (−0.73)	−0.012 (−0.41)		−0.003 (−1.07)	−0.003 (−0.99)
3 ~ 4	0.616*** (4.64)	0.620*** (4.67)		0.048*** (3.31)	0.048*** (3.33)
> 4	−1.822 (−1.58)	−1.874 (−1.63)		−0.224* (−1.77)	−0.221* (−1.76)
Observation	76306	76306		76233	76233

Note: All regressions include controls for other weather indicators, demographic information, and year, month and county fixed effect. Column (1) and (3) show the estimation with -1 ~ 1 deviation as the reference group. Column (2) and (4) show the estimation with -2 ~ 2 deviation as the reference group

***p < 0.01, **p < 0.05, *p < 0.1.

Authors' Contributions. Meng Wang and Cheng Huang designed research; Meng Wang analysed data; Meng Wang and Cheng Huang wrote the paper.

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