A Comparison of the Effect of Diurnal Temperature Range and Apparent Temperature on Cardiovascular Disease among Farmers in Qingyang, Northwest China

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Abstract

Background

Apparent temperature (AT) and diurnal temperature range (DTR) have been extensively used to evaluate the effects of temperature on cardiovascular disease (CVD). However, few studies have analyzed and compared their effects on CVD in less-developed, rural areas of China.

Methods

A case-only analysis was conducted of 43,567 cases of CVD morbidity in Qingyang (Northwest China) in 2011–2017 and the effects of thermal indicators were assessed using distributed lag nonlinear modelling and a Poisson regression model. Data on CVD morbidity originated from the New Rural Cooperative Medical Insurance of Gansu Province and meteorological variables were provided by the Meteorological Science Data Sharing Service.

Results

Both AT and DTR had significant nonlinear and delayed impacts on hospital admissions for CVD. DTR had a stronger and more persistent effect on CVD incidence than AT. Women were more affected by high AT and low DTR than were men, while men were more vulnerable to low AT and high DTR. Temperature effects were not significantly different between people above and below 65 years of age.

Conclusions

These findings provide local public health authorities with reference data concerning sensitive temperature indices for susceptible populations with a view to improving CVD preventive strategies in rural areas.

1. Introduction

Climate change is increasing the incidence of extreme weather events which have a significant impact on public health [1]. It was well-established that extreme weather events are one of the most important factors leading to increased morbidity and mortality [2, 3]. The effects of temperature variations on cardiovascular disease (CVD), the leading cause of death [4–6] and the most preventable noncommunicable disease worldwide [7], have become a focus of research. Previous studies have reported that CVD mortality is highly sensitive to apparent temperature (AT) [8, 9], with nonlinear and reverse J-shaped correlations being demonstrated [10, 11]. Diurnal temperature range (DTR) is generally used to evaluate temperature impacts on CVD. For example, in China [12, 13], Korea [14] and USA [15] DTR was found to have nonlinear relationships with CVD morbidity and mortality.

Most Chinese studies on the relationship between AT and CVD morbidity have been conducted in cities [16, 17], with few studies being performed in rural areas. Farmers are more susceptible to temperature changes compared with urban residents [18]. In rural Northwest China, Ding investigated associations between DTR and blood pressure [19]. Wang studied the impact of ambient temperature (rather than apparent temperature) on CVD in farmers [20]. These studies provided limited information on the differing impacts of DTR and AT on farmers in China. In less-affluent areas of Northwest China where medical facilities are relatively poor, it is necessary to identify appropriate weather indicators for early warning of cardiovascular disease-prone populations. The objective of this study was to assess and compare the efficacy of two temperature indicators of CVD morbidity among farmers in Qingyang between 2011 and 2017. This exploration of the relationship between thermometric variables and CVD risk may help local public health departments develop sensitive temperature indicators for susceptible populations and to instigate alleviation and prevention strategies [21].

2. Materials And Methods

2.1 Location

Qingyang is an eastern city of Gansu Province, Northwest China, at latitude 35°15'N and longitude 106°20'E. It has 700 km² of fertile fields and is known as “the granary of Gansu Province” as well as the city in China with the second largest energy resources. In 2019, the permanent population of Qingyang was 2.28 million, of which farmers accounted for approximately 60%. It has a typically warm temperate continental monsoon climate with distinct alternating cold winters and warm summers (average annual temperatures 9.5–10.7 °C).

2.2 Data collection

Electronic medical records of outpatient admissions for CVD were reviewed at the New Rural Cooperative Medical Insurance of Gansu Province (NRCMI), the government agency responsible for farmer health data collection in Gansu Province. These records encompassed 30 Qingyang city and county hospitals covering 1st January 2011 to 27th March 2017 and included patients' sex, age, hospitalization time, residence, and disease classification. Diagnoses were coded according to the 10th edition of the International Classification of Diseases (ICD-10). CVD classifications included chronic rheumatic heart disease (I05–I09), hypertension (I10–I15), ischemic heart disease (I20–I25) and other types of heart disease (I30–I52). It should be noted that due to a lack of age data, age group analyses were limited to 2014–2017. The study protocol was approved by the ethics committee of Gansu Provincial Hospital. The data is encrypted, because the patient's name, address, and contact information are all hidden and an informed consent waiver is obtained from the ethics committee. The study was performed in accordance with the Declaration of Helsinki.

Meteorological data were collated from the China Meteorological Science Data Sharing Service (<http://data.cma.cn/>). These included mean temperature (T_{mean}), minimum and maximum temperatures

($T_{\max}$ and $T_{\min}$), wind speed (WS), relative humidity (RH), and atmospheric pressure. Weather variables were measured at four fixed-site stations distributed evenly across Qingyang City. Daily mean concentration of air pollutants in the city from 2014 to 2017 was obtained from the China National Environmental Monitoring Center (<http://webinterface.cnemc.cn/>) and included PM2.5, PM10, SO2, NO2, O3 (average concentration for 8 h), and CO (all units $\mu\text{g}/\text{m}^3$).

2.3 Temperature indicators

Several indicators of temperature changes, including DTR and AT, have proven effective. These two independent indicators were compared in this study. DTR was calculated by difference between daily minimum temperature and maximum temperature [22]. AT was calculated from common meteorological indicators using the following equations [23].

$$AT = T + 0.33 \times e - 0.70 \times WS - 4.00 \quad (1)$$

$$e = RH / 100 \times 6.105 \times e^{[17.27 \times T / (237.7 + T)]} \quad (2)$$

Where T is daily mean temperature ($^{\circ}\text{C}$), WS is wind velocity (m/s), e is water vapor pressure (hPa), and RH is relative humidity (%)

2.4 Statistical analysis

Poisson generalized linear regression modelling combined with distributed lag nonlinear modelling (DLNM) was applied to examine the impact of temperature variables on CVD admissions. DLNM using the cross-basis function can simultaneously measure nonlinear exposure-response dependencies and delayed effects [24]. Cubic spline smoothing was adopted to explain variations in the temporal behavior of potential predictors. The smoothed predictors, that is the meteorological indicators, were added in a fashion similar to multiple linear regression. This approach is commonly applied in weather epidemiology and has been used in similar studies [25,26]. The general model $Y_t \sim \text{quasi-Poisson}(\mu_t)$ was as follows:

$$\begin{aligned} \text{Log}(\mu_t) = & \alpha + \beta(X_{t,l}) + ns(\text{Temperature}_t, df) + ns(\text{Time}, df) + \text{Holiday} \\ & + ns(LP_t, df) + ns(WS_t, df) + ns(RH_t, df) + \text{Dow} \end{aligned} \quad (3)$$

where Y_t is the daily observed count of emergency visits to CVDs for day t ($t = 1, 2, 3, \dots, 21$), α is the intercept, $X_{t,l}$ is the cross-basis matrix of temperature indicators in DLNM (AT and DTR were compared in two dependent models), L is lag days, β is the vector of the coefficients for temperature variations, LP is local pressure, WS is wind speed, RH is relative humidity (meteorological factors were applied in the model using a natural cubic spline to control their potential implications), ns is natural cubic spline, and

df is degrees of freedom, while the dummy variables DOW (day of the week) and Holiday were used to control the impact of the sampling day.

Previous studies proved that long-term tendency, local pressure, relative humidity, and wind speed were potential confounders having an impact on CVD outpatient visits [27-29]. Natural cubic splines were applied in DLNM to estimate the independent impact of temperature variations on outpatient admissions for CVD (three equally spaced knots were placed per year for the continuous dependent variables). A 3-df natural cubic spline was used to control the effects of humidity, wind speed, and local pressure [30,31], 4-df to eliminate the impacts of mean temperature [32,33], and 7-df to remove long-time tendency [32,34]. Some studies have demonstrated that air pollutants are also associated with CVD [35]. However, in rural regions the impact of air pollution does not appear to be significant [36,37] as concentrations of air pollutants are very low [38]. Furthermore, air pollutant sensitivity analysis was performed (Figure S1, see additional file 1) and no differences were observed. Air pollution was not included in the model in order to avoid overfitting. The degrees of freedom for DTR and lag in the cross-basis matrix were chosen according to a modified Akaike Information Criterion (Table S1, see additional file 2): 4-df for AT and 3-df for lag in AT cross-basis matrix and 6-df for DTR and 3-df for lag in DTR cross-basis matrix.

All data were stratified according to sex (male and female) and age (adult and old) for subgroup analyses. The threshold for age was set at 65 years—China’s retirement age. The median value of the temperature indicators was used as the reference to calculate relative risk (RR) with a 95% confidence interval. Cumulative lag effect of the thermal indicators was assessed with a 21-day lag [39,40]. Various lag periods (0, 3, 7, 14, and 30 days) were examined to determine the impact of temperature indicators on CVD visits. The impact of lagx denotes the effect of DTR on CVD incidence after x days. Previous studies suggest that there is a cumulative lag effect of DTR on CVD admissions [31,41]. Most studies used a lag of 21 or 28 d [25,40,42]. However, the current study assessed a lag of zero to 30 days to evaluate the cumulative effect of a month-long lag. Moreover, to assess the robustness of the model, several df of the meteorological variables were evaluated in a sensitivity analysis, including temperature (df = 3–5), relative humidity (df = 4–6), local pressure (df =4-6) and wind speed (df= 3-5), (Fig S2, see additional file 3). All statistical analyses and chart preparation were performed using the ‘dlnm’ package in the R v.3.4.1 statistical software.

3. Results

Table 1 Summary statistics for daily variables and cardiovascular diseases (CVD) cases in Qingyang, China, 2011-2017

Descriptive statistics for CVD cases and meteorological variables are presented in Table 1. A total of 43,567 cases of CVD were included in the study from 2011 to 2017, of which approximately 54% were male and 46% were female. The subgroup categorized by age from 2014 to 2017 encompassed 71% of all cases (due to the incomplete age data). Adult patients accounted for 41% of these cases and old patients accounted for 59%. The mean apparent temperature was 8.13°C (with a large standard deviation

Variable	Sum	Mean	SD	Frequency distribution					of
				Min	P(25)	P(50)	P(75)	Max	
All	43567	20.5	15.08	0	9	18	29	211	
Man	23483	11.05	9.27	0	4	8	16	97	
Woman	20083	9.45	6.87	0	4	8	13	114	
<65 years	16736	14.16	9.58	0	7	13	20	59	
≥65 years	14263	12.07	7.32	0	7	12	17	65	
Mean temperature(°C)	/	10.15	10.14	-14.7	1	11.3	19.2	30.6	
Relative humidity(%)	/	65.33	16.99	14	53	66	79	100	
Pressure(hpa)	/	892.87	6.27	877.6	887.8	892.7	897.6	916.3	
Wind speed(m/s)	/	1.84	0.72	0.3	1.4	1.7	2.2	5.9	
Rainfall(mm)	/	1.47	5.32	0	0	0	0	67.7	
AT(°C)	/	8.13	12.08	19.75	-2.89	8.95	18.99	32.41	
DTR(°C)	/	12.82	5.46	1	8.7	12.9	16.9	29.6	

12.08°C) ranging from -19.75°C to 32.41°C, being slightly lower than the mean temperature (10.15°C). The average DTR was 12.82°C (with a moderate standard deviation of 5.46°C)

Fig. 1 shows the 21-day cumulative lag effect of AT and DTR on the RR of CVD admissions in all groups. Overall, the impact of DTR on CVD was greater than of AT for all subgroups. The relationship between the temperature variables and the RR of CVD resembles a bimodal function. Table 2 (see additional file 2) shows the RR of CVD for AT and DTR. The first peak was evident at AT -4°C or DTR 6°C (AT 1.083, DTR 2.243) and the second at AT 20°C or DTR 19°C (AT 1.596, DTR 1.875). DTR posed more of a risk of CVD incidence to men than to women when DTR was at a high of 19°C (male 2.061, female 1.662), while this was reversed at a low DTR of 6°C (male 2.167, female 2.491). Women suffered more risk than men when AT was ≥ 20°C (AT 20°C: male 1.125, female 2.220), while the opposite held when AT ≤ 0°C (AT -4°C: male 1.348, female 0.859). In the age-specific study, the maximum CVD RR occurred at the lowest DTR (adult 2.327, old 2.368) and then increased to its maximum when DTR was 19°C (adult 2.527, old 2.752). The impact of AT on RR of CVD was most significant at 0°C (adult 1.508, old 1.497) and there was no significant difference between the age groups.

The single lag effect of the temperature indicators on RR of CVD was examined by contour map (Fig. 2, reference 12°C). Overall, the AT models demonstrated a 2% increase in RR when AT rose from 16°C to 24°C, but this disappeared after about two weeks. A weaker and shorter cold effect was observed from -10°C to 0°C. The heat effect also lasted longer. However, the RR of CVD admission decreased gradually by 1–5% across the lag days when DTR was 6°C, while a 3% increment was sustained for a month when

DTR was 19°C. There was also a protective effect at high DTR $\geq 25^{\circ}\text{C}$. Overall, DTR exerted a stronger and longer single lag impact on RR of CVD incidence in all people compared with AT (AT 1.020 lasting for 15 days; DTR 1.05 lasting for 22 days).

The AT single lag effect was more significant and longer with women (1.03) than with men (1.01) at AT above 20°C, but there was no effect at colder temperatures. The adverse effects of DTR for men were greater and longer than for women at both low and high DTR (men 1.04 for one month, women 1.04 for half a month). Overall, the effect of AT on men was gradually attenuated and disappeared after five days, while the effect of DTR was longer and stronger. However, the lag effect of AT was more obvious on women. Men suffered a longer and stronger RR of CVD when exposed to high DTR than did women, while women experienced a longer lag effect at high AT than men.

A comparison of adult vs. old CVD incidence showed that DTR exerted a stronger single lag effect on CVD for both adults and old people (AT 1.04, DTR 1.075). Both age groups exhibited the same pattern of impact of DTR on CVD (adult 1.075, old 1.075). However, adults experienced a greater risk in days of low AT compared with the elderly (adult 1.04, old 1.02). The protective impact of temperature occurred at the extremes: below -10 °C and above 30 °C for AT, but only at high DTR. The contour map of the effect of AT on age group was unimodal, while DTR was bimodal.

4. Discussion

To our knowledge, this study is the first to compare and analyze the effects of DTR and AT on the onset of CVD in rural areas. Both AT and DTR had significant nonlinear, delayed effects on CVD morbidity. Whether cumulative or single lag, the effect of DTR on CVD incidence was greater and more persistent than AT in all groups. Women were more affected by AT above 20°C than men, but this was reversed at AT below 0°C. However, men appeared to be more vulnerable to high DTR (19°C) than women, while this was reversed at low DTR (6°C). There was no difference in cumulative lag impact on age subgroups in both the DTR and AT models, but the single lag impact of AT on adult men was greater than on the elderly.

We found that both DTR and AT had significant impacts on cardiovascular morbidity, while the relationship between the thermal variables and risk of CVD was nonlinear with M-shaped curves. However, this was inconsistent with many prior studies that reported relationships between AT and RR of CVD having reverse J-shaped curves [10, 11, 16]. This was also the case for DTR. Youn-Hee demonstrated a positive linear relation between DTR and Emergency Room admissions in Korea [14, 34]. J-, V- and U-shaped correlations between DTR and CVD have been demonstrated in USA [15], China [12, 13], and Korea [14]. These differences may be due to geographical effects, climatic characteristics, differences in use of cooling and heating equipment, and housing types [13].

Overall, DTR was associated with a greater risk and disease burden of CVD (cumulative lag effect: DTR 2.37, AT 1.62). Few studies have compared the extent of the effects of AT and DTR. Increases of 33% and 3% in cumulative DTR-related risk of CVD were associated with 8.2°C and 1°C ranges in southwest China

[41] and Korea [14], respectively. The risk of CVD mortality increased by 7% and 14% with 7°C and 8°C increases in AT in Iran [10] and Copenhagen [11], respectively. A study conducted in Virginia, USA, showed that DTR was associated with a higher incidence of Emergency Department visits than were AT and mean temperature [42]. These studies support the current finding that the RR of CVD was stronger and longer under the influence of DTR than AT. The differences in the impact of AT and DTR on CVD can be attributed to their differing pathogenesis. DTR affects cardiovascular mortality through alterations in autonomic nervous functions. A large DTR can induce disturbances of the autonomic nervous system, resulting in elevated heart rate and decreased heart rate variability, which indicate impacts on the sympathetic and parasympathetic nerves and on sinoatrial node frequency (i.e., regulation of neurohumoral factors of the cardiovascular system)[14]. Furthermore, heart rate, cardiac workload and blood pressure changes triggered by wider temperature changes have been shown to contribute to the onset of CVD [19, 20]. AT-related impacts on CVD can be explained by that body's circulatory system responding to high or low temperatures by releasing platelets into circulation and the increasing red and white cell counts, blood viscosity and plasma cholesterol resulting from water loss and reduced plasma volume under hot conditions [21]. The direct effects of DTR on the autonomic nervous system and the indirect effects of AT on the circulatory system explain the differing impact and lag periods of these temperature parameters.

Danet et al. demonstrated that a 1.3% increase in fatal coronary events was associated with a 1°C decrease in DTR in USA [42], while a 1°C increase in mean AT was associated with a 2.4% increase in cardiovascular events in Portugal [8]. These studies suggest that AT is associated with a higher risk of CVD than DTR, which is not consistent with the current study. Possible reasons for this inconsistency are differences in population demographics, exposure conditions, climatic characteristics, and climate-related behaviors [11, 31, 44]. The current study area, Qingyang located in the Loess Plateau, has a continental climate which creates a large DTR but a relatively moderate AT. People in Qingyang suffer a greater risk of CVD due to DTR rather than AT because they are exposed to large temperature differences rather than extreme temperatures. Furthermore, farmers, especially those most susceptible to cardiovascular disease, tend to be more vulnerable to DTR because of their lack of awareness of how to protect against extreme DTR. Moreover, the weather forecast broadcasts temperature rather than DTR. People suffer more adverse effects from DTR than AT because it can be hard to respond quickly to sudden temperature changes, while people can deal with high and low temperatures by adding or removing clothing in advance, using air conditioning, and so on. It is proposed that relevant departments should broadcast DTR forecasts for the benefit of CVD-susceptible populations.

Another interesting finding in this study was that women were susceptible to a slightly higher AT than men, whereas, when AT was below 10°C men were at higher risk. Previous studies are consistent this finding, confirming that women have a higher risk of CVD in hot conditions, while men are at greater risk in cold conditions [10, 15, 27]. This may be due to women being more susceptible to arrhythmia, ischemia, and high blood pressure, all of which are exacerbated by extreme hot and cold temperatures [21, 45]. Conversely, hot conditions increased coronary events in men in San Paulo while low temperatures with up to two lag days increased women's mortality risk in a subtropical climate zone in

China [45]. Meta-analysis performed by Moghadamnia et al. on data from Mohamamad et al. confirmed their finding of no difference in the impact of hot and cold temperatures on CVD in the two genders [28, 45]. Basu suggested that different gender temperature effects were the result of location and population [46]. A European study demonstrated that clothing plays a significant role in such differences and that there are also biological gender differences in thermoregulation [47]. Thus, women should pay more attention than men to protective measures when $AT > 20^{\circ}\text{C}$. A further issue is that farmers, whether women or men, have increased exposure to high AT during the harvest and sowing seasons in mid-April and mid-September [48–50] when temperatures range from 20 to 25°C (Fig S3, see additional file 4). Both men and women work during these periods but women bear the greater risk of CVD [51]. Again, clothing was shown to play a significant role in this gender difference [30].

DTR-related RR of CVD in men was higher than in women at high DTR (20°C), while this was reversed at low DTR (5°C). Epidemiological studies have proven that CVD mortality in females was more strongly associated with DTR than in males in China [13, 52], Korea [10], and Japan [53]. This is in line with the present results at low DTR, but conflicts with the results at high DTR. This sex-related difference may be attributable to demography-related behavioral differences and geographical effect modifiers [10]. The present data were obtained from the NRCMI in order to examine a population of farmers. In rural Qingyang more than 30% of farmers are migrant workers [54–56] and most of them are men whose work is usually outdoors, while the women generally work at home. The woman could, therefore, be more flexible at work compared with the men in the face of adverse weather conditions, possibly decreasing or avoiding exposure during high-DTR days, while the men remained exposed to the adverse temperatures. Consequently, on suitable days with low DTR, women may go out to work along with the men but they also bear a greater CVD risk due to sex-related physical differences [51]. However, the men had longer exposure on the high-DTR and low-AT days, leading to a higher risk of CVD compared with women. A previous study has shown that greater DTR exposure or weaker intrinsic susceptibility factors may result in increased risk [14]. Different subgroups and mortality categories were sensitive to different temperature indicators [57], which also illustrates why women were sensitive to high AT and men were sensitive to high DTR.

To our knowledge, this is the first study to compare and analyze the impact of DTR and AT on CVD. The relationship between thermal variations and morbidity was studied in a developing rural area of Northwest China (Qingyang). This study used validated and credible data originating from NRCMI of Gansu Province which recorded all outpatient visits by farmers. The results provide information for local government to enhance the protection of citizens of rural and less-developed areas. This analysis has both strengths and limitations. Firstly, only one area was selected as representative of typically poor rural regions. Further studies need to be conducted to evaluate DTR impact in other rural regions and confirm these findings. Secondly, the effects of characteristics such as personal behavior, medical history and living conditions were not considered due to their absence from the available data. Thirdly, the assumption that all individuals were exposed to the same thermal environment was a generalization. Finally, the retrospective data collection method may allow biases from diagnostic and coding inaccuracies.

5. Conclusion

This study investigated and compared the effects of DTR and AT on the incidence of CVD in a rural and less-developed area of Northwest China using DLNM. The effect of DTR was larger and more persistent than AT. Women were more sensitive (and for longer periods) to high AT and low DTR compared with men, while men were more susceptible to low AT and high DTR. However, there was no significant difference in the effects of the two temperature indices on CVD in different age groups. Since temperature-associated adverse effects are potentially modifiable via preventive measures and lifestyle changes, these findings may have important implications for the prevention of cardiovascular disease in less-developed rural areas.

Abbreviations

DTR: Diurnal temperature range; AT: Apparent temperature;

CVD: Cardiovascular diseases;

NRCMI: New Rural Cooperative Medical Insurance of Gansu Province;

DLNM: distributed lag nonlinear model. RR: relative risk of CVD.

Declarations

Availability of data and material

The datasets used and/or analysis during the current study available from the corresponding author on reasonable request.

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Authors' contributions

Zhai contributed to design the conception of the study and analysis and interpret the data. Qi contributed to the acquisition of data and drafting the article, and the important intellectual content was revised by Zhang. Zhou and Wang participated in the final approval of the version to be submitted. All authors have approved the manuscript.

Ethics approval and consent to participate

The study protocol was approved by the ethics committee of Lanzhou University of Technology. The data is encrypted, the patient's name, address, and contact information are all hidden and informed consent waiver obtained from the ethics committee. The study was performed in accordance with the Declaration of Henlsinki.

Consent for publication

All consent.

Competing interests

The authors declare that they have no competing interests.

Authors' information

Not applicable.

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Figures

Figure 1

The 21-day cumulative lag effect of AT and DTR on the RR of CVD admissions in all groups

Figure 2

The contour map of single lag effect of the temperature indicators on RR of CVD

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