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The effect of apparent temperature on hospital admissions for cardiovascular diseases in rural areas of Pingliang, China

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Abstract
Introduction and Objective. There is a well-reported association between temperature and the relative risk (RR) of cardiovascular disease (CVD) in urban areas in China. However, insufficient research has been performed in rural areas. The aim of the study was to analyze the association between apparent temperature (AT) and the RR of CVD hospital admissions in rural areas of Pingliang, northwest China.
Materials and method. Daily data and weather conditions were collected in Pingliang from 2014–2015. The median value of AT was selected to estimate the RR of CVD, and the distributed lag nonlinear model (DLNM) used to examine the relationship between AT and the RR of CVD admissions for up to 21 days.
Results. The results showed a nonlinear relationship between AT and the RR of CVD admissions. Regarding the heat effect, there was a protective effect. Meanwhile, the cold effect on the RR of CVD admissions appeared at day 0 and persisted until day 21, resulting in a cumulative RR of 2.304 (95%CI: 1.809–2.936) compared with the median value of AT, and the maximum RR appeared at about -5 °.The cumulative RR values of CVD on men and adults were more sensitive than those on women and elders in the cold effect.
Conclusions. AT is associated with the hospitalization of CVD patients. Both gender and age factors were associated with the increase in RR of CVD admissions. More preventive measures should be taken to avoid this adverse effect.

Key words
cardiovascular disease, rural areas, apparent temperature, distributed lag nonlinear model

Abbreviations
RR – relative risk; **CVD** – cardiovascular disease; **AT** – apparent temperature; **DLNM** – distributed lag nonlinear model; **DTR** – diurnal temperature range; **NRCMS** – New Rural Cooperative Medical Scheme; **AIC** – Akaike's information criterion; **CI** – confidence Interval

INTRODUCTION

With the increasing changes in global climate, the effects of temperature on human health have been the focus of many studies. Extremely high and low temperatures apply pressure on the environment and cause physiological stress in humans, which is manifested in morbidity and mortality [1, 2, 3, 4]. Therefore, extreme temperature represents one of the risk factors for mortality and morbidity. Many researchers have studied the effects of high or low temperature on mortality or cardiovascular disease (CVD) hospitalization [2, 5, 6, 7, 8, 9]. An unhealthy lifestyle made the impact of cardiovascular disease risk factors on the health of residents increasingly significant and increased the incidence of cardiovascular disease (CVD). Currently, cardiovascular disease (CVD) is the first cause of death among urban and rural residents in China, with a mortality rate of 46.66% in rural areas and 43.81% in urban areas. The economic burden of cardiovascular disease (CVD) on residents and society is continuously increasing [10].

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Previous studies have mostly used ambient temperature as an indicator of the changes in temperature; for example, Kirran et al. [11] showed a U-shaped association between cardiovascular disease (CVD) admissions and temperature. In another study in Queensland, Australia [12], a decreasing trend was shown in the relationship between cold temperature and cardiovascular disease (CVD) hospitalizations, while high temperature had an increasing impact on cardiovascular disease (CVD) admissions. A study by Cui et al. in Hefei, Anhui Province, China, showed that males and adults were more susceptible to low temperature, while females and elders were more susceptible to high temperature [13]. A significant association was shown between mortality and high temperature in the work of Panayiotis et al. [14]. The relative risk (RR) of myocardial infraction (MI) admission increased in elders under low temperature conditions. However, the diurnal temperature range (DTR) only contains the temperature factor, apparent temperature (AT), which is defined as the individual's perceived air temperature, given the humidity, and used to estimate the extra pressure on the body in the heat condition based on the efficiency of evaporative cooling [8, 15, 16].

Most previous studies on cardiovascular disease (CVD) were performed on urban dwellers in China [3, 11, 17, 18, 19].

In a study by Ding et al., the effect of the diurnal temperature range (DTR) on mortality was evaluated in a high plateau city in China [20]. It is valuable to study the relative risk (RR) of cardiovascular disease (CVD) in rural areas. To this end, the current study analyzed the association between apparent temperature (AT) and the relative risk (RR) of cardiovascular disease (CVD) hospital admissions in rural areas in Pingliang, northwest China, using the distributed lag nonlinear model (DLNM). The results obtained could be used to guide the allocation of health resources, as well as the development and implementation of adaptive strategies in regions at relative risk (RR) of cardiovascular disease (CVD).

OBJECTIVE

The aim of the study was to analyze the association between apparent temperature (AT) and the RR of CVD hospitalization in rural areas in Pingliang, northwest China. The findings could help to promote preventive measures against CVD and reduce the adverse impact of AT on the CVD hospitalization rate.

MATERIALS AND METHOD

Study area. The study was performed in the area of Pingliang, located in eastern Gansu province, northwest China, adjacent to Shanxi and Ningxia provinces, at the intersection of the Qinghai-Tibet, Ordos and Loess Plateaus. The area is located between 34°54' – 35°46' north latitude and 105°20' – 107°51' east longitude [21]. The climate is temperate semi-arid and semi-humid continental monsoon climate, a mild climate with sufficient sunshine. With the influence of Liupan Mountain, which is an important watershed in the eastern part of the region, and the special topography of small cities, the climate of this area has certain differences [22].

Data collection. Daily hospital admission counts between 2014–2015 by the New Rural Cooperative Medical Scheme (NRCMS), the government agency in charge of health data collection in Gansu Province, were used in the study. The NRCMS Time-series meteorological data were obtained, including the following areas: temperature, relative humidity, rainfall, speed and sunshine, spanning the analysis period (2014–2015) from the Gansu Meteorological Bureau. AT was calculated using the meteorological data as follows (Yi et al. 2019):

$$AT = Ta + 0.33 * e - 0.70 * WS - 4.00$$
$$e = Rh/100 * 6.105 * \exp\,(17.27 * Ta/(237.7 + Ta)$$

where Ta denotes the ambient temperature, e – water vapour pressure, WS – wind speed (m/s), and Rh – relative humidity.

Statistical analysis. A distributed lag nonlinear model (DLNM) with natural cubic spline-natural cubic spline was used to assess the effect of apparent temperature on the RR of CVD hospital admission in different age and gender subgroups with different lags. All the environmental variables (temperature, relative humidity, local pressure, speed, sunshine and rainfall) and day of the week were controlled in the model. A 21-day lag period was used to capture the delayed effect of AT. The model used was as follows:

$$Log[E(Y_t)] = \alpha + \beta(AT_{t,l}) + ns(Time,\ 7)$$
$$+ ns(Sun_t,\ 3) + ns(rh,\ 3) + DOW + Holiday$$

where t is the day of observation ($t = 1, 2, 3\ldots21$), $E(Y_t)$ – the daily number of CVD admissions, α – the intercept, $AT_{t,l}$ – the 'cross-basis' matrix of AT in DLNM, L – lag days, β – the vector of the coefficients for AT, ns – the natural cubic spline to control potential confounding effects by fitting their degree of freedom (df) trend, Time – the long-term tendency, rh – relative humidity on day t, and DOW – day of the week. DOW and Holiday were controlled as dummy variables in the model. Akaike's information criterion (AIC) to select the df for AT and lag, so that we selected df with the lower AIC, 6 df for AT and 6 df for lag, but the fit was not good. Finally, 4 df for AT and 4 df for lag were more suitable to for use in the current DLNM model.

The population was stratified according to age (adult and old) and gender (male and female) to assess the potential effect. Furthermore, the cold and heat effect of AT was also investigated in each subgroup.

Sensitivity analysis. Since it was difficult to determine the appropriate maximum lag days and df, a series of sensitivity analyses were performed to examine the robustness of the model. In order to check whether using 21 lag days were sufficient to examine the delayed effect, the lag days were changed from 20 to 22. In addition, we also changed the df for sunshine, relative humidity and time from 3–5, 3-5 and 6–8, respectively. All data analysis was performed using the 'dlnm' package in R software (version 4.1.1).

RESULTS

The weather and CVD hospital admission data from 1 January 2014–31 December 2015 are listed in Table 1. The mean daily total hospital admission cases were 24.68813 (SD = 11.33774) among the population. Female patients and adults accounted for 43.9% and 53.4% of the total number of hospitalizations, respectively. The proportions of CVD cases were higher in female and adults than in males and the elderly.

The cumulative lagging effect of cold and heat in the overall population on the CVD hospital admission compared with the median of AT is listed in Table 2. Regarding the effect of cold, the RR of hospital admission significantly increased in the 5th percentiles of AT, in the higher lags (0–14 and 0–21), compared with the reference with the median AT (9.41 °). As for the heat effect, the RR decreased as the lag time increased in the 95th percentiles of AT compared with the median.

Figure 1 shows the cumulative effect of AT on the RR of CVD along the lag days and AT. For low AT values, the RR greatly increased with the increase in the lags and then decreased. The maximum RR for CVD hospital admission occurred when AT was -10 ° at lags of 5 days. The cumulative exposure-response curve and AT distribution in Pingliang are shown in Figure 2. The curve shows how the RR increased as temperature increased and reached a maximum at about -5 °, after which a gradual downward trend could be seen. There was a protective effect when the temperature exceeded

Table 1. Summary of statistics for cardiovascular disease hospitalization and meteorological variables in Pingliang, China, from 1 January 2014 - 31 December 2015

	mean	sd	0%	25%	50%	75%	100%
V1	24.68813	11.33774	2	16	23	32	71
V1man	10.76252	5.243167	1	7	10	14	31
V1woman	13.92561	7.175465	1	9	13	18	44
V1adult	12.94134	6.411911	1	8	12	17	39
V1old	11.72389	6.085083	1	7.5	11	15	39
tt	10.67668	8.777014	-8.2	3.25	11.9	18.7	26.9
AT	8.378683	10.38444	-12.4891	-0.67744	9.410327	17.7783	28.2135
rh	61.40629	18.9678	16	47	60	76	99
Local pressure	866.1518	5.096516	852.8	862.1	865.7	869.8	881.8
rainfall	1.464664	4.711912	0	0	0	0.1	52.3
speed	1.872675	0.575961	0.5	1.5	1.8	2.2	4.6
sunshine	6.278255	4.158853	0	2.2	7.3	9.4	13.1

V1 – total hospital admission; V1man – number of man hospitalizations; V1woman – number of woman hospitalizations; V1adult - number of adult hospitalizations, V1old - number of old hospitalizations; tt – temperature; AT – apparent temperature; rh - relative humidity

Table 2. Cold and heat effect on relative risk of cardiovascular disease hospital admission during the lag days for the entire study group.

Lag	Cold effect (AT5 vs Median)	Heat effect (AT95 vs Median)
0	1.041(0.862, 1.257)	0.99(0.841, 1.164)
0-3	1.131(0.969, 1.32)	0.745(0.643, 0.864)
0-7	1.432(1.224, 1.676)	0.672(0.566, 0.797)
0-14	2.04(1.701, 2.446)	0.617(0.501, 0.759)
0-21	2.304(1.809, 2.936)	0.579(0.466, 0.721)

9.41 °. The red line shows the RR, and the grey area indicates the upper and lower limits.

Table 3 shows the relationship between the 5 percentiles of AT and the 95 percentiles of AT and RR of CVD admissions in the cumulative effect at different lags (lag 0, lag 0–3, lag 0–7, lag 0–14, lag 0–21) for different gender and age subgroups. For the cold effect, the RRs continued to increase with the increase in the number of lag days and reached the maximum at 21 in all study subgroups. Among them, the RR of CVD was more significant in males and adults than in females and the elderly [male: RR 2.869, Confidence Interval (CI) 1.993, 4.131; female: RR 1.951, CI 1.411, 2.697; adult: RR 2.597, CI 1.852, 3.591; eldly: RR 1.982, CI 1.389, 2.83]. On the contrary, the RR of CVD decreased with the increase in lags in the heat effect.

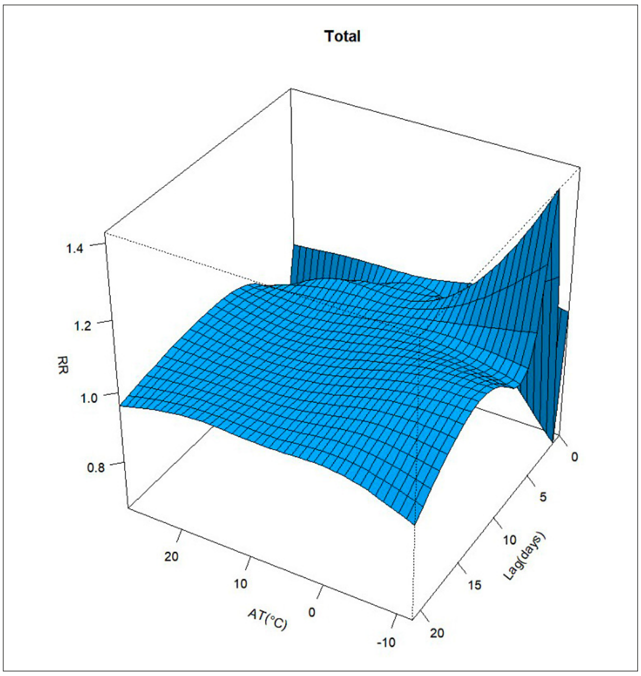

Figure 1. Three-dimensional plot of the association between AT and RR of CVD hospitalization over 21 lag days

Table 3. Relative risk of cardiovascular disease hospital admission for gender and age groups in the 5th percentiles of AT and the 95th percentiles of AT

	AT	Lag 0	Lag 0-3	Lag 0-7	Lag 0-14	Lag 0-21
Male	-8	1.051(0.792, 1.396)	1.145(0.906, 1.446)	1.525(1.202, 1.935)	2.344(1.782, 3.083)	2.869(1.993, 4.131)
	23	1.009(0.788, 1.293)	0.709(0.566, 0.889)	0.653(0.504, 0.846)	0.652(0.476, 0.895)	0.584(0.42, 0.813)
Female	-8	1.035(0.804, 1.333)	1.122(0.912, 1.379)	1.368(1.11, 1.688)	1.832(1.437, 2.336)	1.951(1.411, 2.697)
	23	0.975(0.786, 1.206)	0.769(0.632, 0.936)	0.684(0.544, 0.86)	0.587(0.446, 0.774)	0.572(0.428, 0.765)
Adult	-8	1.26(0.972, 1.634)	1.223(0.988, 1.513)	1.564(1.259, 1.943)	2.297(1.788, 2.95)	2.579(1.852, 3.591)
	23	1.039(0.828, 1.304)	0.773(0.629, 0.95)	0.756(0.595, 0.961)	0.636(0.476, 0.849)	0.589(0.434, 0.799)
Elderly	-8	0.841(0.639, 1.107)	1.02(0.814, 1.278)	1.272(1.011, 1.6)	1.761(1.351, 2.295)	1.982(1.389, 2.83)
	23	0.947(0.749, 1.195)	0.719(0.581, 0.89)	0.601(0.47, 0.768)	0.611(0.453, 0.824)	0.581(0.425, 0.795)

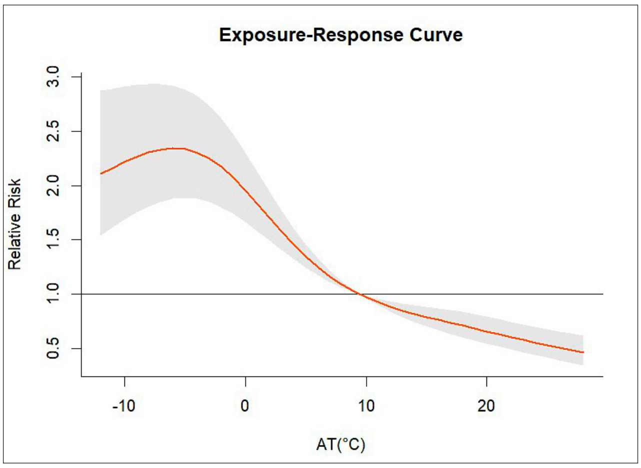

Figure 2. The exposure-response curve between AT and RR of CVD hospitalization in Pingliang, China

DISCUSSION

The analysis performed in this study revealed a significant association of high relative risk of CVD hospital admission at low AT among the study population. For all groups, the RR of CVD admissions increased with a cumulative lag effect up to 21 days in the cold.

The findings obtained showed a considerable effect of low AT, which is consistent with the results of several prior studies on the AT-mortality relationship in other areas [23]. A previous study in Kintampo, Ghana, investigated how the RR increased in the lowest AT of 18 ° from 2–4 lags, and the highest RR was observed 3 days after exposure [24]. Mohammad et al. showed that low temperature (8.2) had significant impacts on CVD mortality [25]. Although the effect of AT on mortality was not examined in the current, mortality and hospital admission are related. A previous study suggested that the cold effect (9.13 °) is a significant association with the increased RR of CVD hospital admissions [12]. When exposed to cold, the cold effect increases the RR of CVD and causes vasoconstriction, increasing blood pressure and heart rate [26].

The results of this study demonstrate the protective effect of heat. A study in Tianshu, Gansu Province, China, showed a protective effect of high temperature (38.2 °) at 2–5 lags [27], while a study in Australia showed that the heat effect (33.54 °) is not associated with the increased RR of CVD hospitalizations [12]. However, other prior studies showed that RR of CVD increases with the heat effect (25.2 °), as in the study by Whanhee et al. in northeast Asia [28]. In another study on the population from 10 Asian cities, the exposure-response curve of the heat effect (20–30 °) showed a nonlinear and sharp increase [23]. In Lisbon and Porto, Portugal, the mortality risk increased as AT increased [15]. Possible reasons behind this variation might be the living habits and climatic conditions. The presented study compared the heat effect, in the 95th percentiles of AT (23 °), with the median of AT (9.41 °); the high AT in this study was lower than that in other studies [8, 16, 23, 24], which might explain why the protective effect of heat appeared in the current study. In addition, the study covered the rural area of Pingliang; rural areas are usually cooler than urbans with less anthropogenic activities, lower number of high buildings and more green plants, which may be beneficial in hot weather for the countryside compared with cities. Previous studies suggested that there exist differences in temperature-related health burdens between urban and rural areas [29]. Moreover, farmers carry out agricultural activities on suitable days, which makes them flexible and selective at work, leading to less exposure.

In this study, a similar increasing trend for the cold effect and decreasing trend for the heat effect were demonstrated in the gender and age groups. Regarding the gender groups, the results obtained showed that the increase in RR of CVD was greater in men than in women, which indicates that men become more susceptible to cold temperature than women in the study area. The work of Liu et al. reported that males were more sensitive to acute myocardial infarction (AMI) at a low temperature (7.1 °) [30]. In another study, men were identified as the most vulnerable group to suffer from heart disease due to a large temperature change [1]; however, many studies have reported that females are vulnerable to AT. At the lowest AT (18 °), the RR of mortality was higher for females compared with a reference temperature at 2–4 lags [24]. In Tianshui, the cumulative RR of CVD on females was more significant than that on males in a cold temperature [27]. This was explained by the study of Rasool et al. which showed that men contribute to more outdoor jobs and activities, which is more likely to lead to more exposure at a high temperature (33.3 °) [31]. Another reason is coexisting diseases, such as stroke, which is significantly higher in males than in females [32].

As for the age group, the results of the findings in the current study show that the RR of CVD in adults was significantly higher than in the elderly in the cold effect, while there was a protective effect of heat. However, this was not consistent with several studies, which revealed that the RR of CVD in the elderly (> 65 years) was higher than that in adults (< 65 years) [33]. A study in the most populous tropical city in Vietnam showed that the RR of CVD admissions in people aged 0–64 was higher than that in those aged > 64 in the heat (29.6 °) [34]. Another study in Shenyang, China, showed that the elderly were more vulnerable than adults to the risk of myocardial infarction (MI) hospitalization increased in low temperature (-20 °) at 1–8 lags [35]. Living habits and environment factors are among the possible reasons for this – adults who prefer to smoke, drink and overeat may have an increased RR of CVD [36]. Exposure to low temperature may cause coronary spasms, chest pains, and even myocardial infarction [37]. In comparison, a study in Henan Province, China, revealed that the shorter and longer night sleep duration may be negatively associated with ideal cardiovascular health (ICH) for the elderly. The elderly are more prone to suffer from a poor sleep quality, which may lead to adverse effects [38].

To the best of the knowledge of the authors of the current study, this is the first study to assess the relationship between AT and the RR of CVD hospitalization in Pingliang using a DLNM model. In addition, AT was selected as a reference value to calculate the impact of low and high AT on the RR of CVD admissions. The results of this study could provide governments with strategies to cope with the increased hospitalization rate, and improve the ability to prevent cardiovascular diseases, i.e., notices are issued in a timely manner to remind residents to guard against extreme temperature changes. The presented results may have important implications for improving our understanding of climate-change related health impacts, and for a more efficient allocation of local public health resources.

The study has several limitations. First, several previous studies suggested that CVD was attributed to air pollution; however, since the air quality in Pingliang is good for most of the year [39], the air pollution factor was not included in this study. Second, the effects of individual differences, such as the medical history, living habits and social status, were not included in the research because of lack of relevant data. Finally, it is inaccurate to assume that all the patients have a similar exposure. Due to the usage of heating and air conditioning, indoor and outdoor temperature measurements will differ.

CONCLUSIONS

The study explored the effect of AT on the RR of CVD hospitalization in Pingliang, China. A nonlinear relationship was observed between AT and the RR of CVD admissions. For the cold effect, the RR of CVD hospital admissions increased with the increase in lag days, and this cold effect was more significant in males and adults than in females and the elderly. In contrast, there was a protective effect of heat in the entire study group. These findings could help to promote preventive measures against CVD and reduce the adverse impact of AT on the CVD hospitalization rate.

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