Preplanned Studies

Associations Between Air Temperature and Daily Varicella Cases — Jinan City, Shandong Province, China, 2019–2021

Guijie Luan[1,2]; Yuehua Hu[1]; Meng Chen[2]; Meiying You[1]; Chengdong Xu[3]; Dapeng Yin[4]; Jianjun Liu[1]; Hongyan Yao[1,#]

Summary

What is already known about this topic?

The impact of air temperature on varicella has been studied, but there is limited research exploring its effect on varicella by gender and age group.

What is added by this report?

We conducted a time series analysis to examine the differential effects of air temperature on varicella infection across different demographic groups. Our findings indicate that lower temperatures have a more pronounced influence on varicella incidence among males and children compared to females and adults.

What are the implications for public health practice?

These findings can assist in identifying populations that are vulnerable to temperature-related varicella and in guiding the implementation of effective measures for varicella control.

Varicella, an acute respiratory infectious disease primarily affecting children, has been shown in several studies to be influenced by air temperature (*1–2*). However, little research has been conducted on the effects of air temperature on varicella incidence based on gender and age groups. This study aims to examine the association between air temperature and varicella and identify any group-specific differences in temperature-related risk. A distributed lag non-linear model (DLNM) was utilized to assess the impact of air temperature on varicella incidence in Jinan City, Shandong Province from 2019 to 2021. Our findings indicate that both gender and age exhibit diverse impacts of higher and lower temperatures on varicella incidence. Lower temperatures have a greater effect on varicella incidence in males compared to females, particularly within 1–4 days of exposure. The relative impacts of higher and lower temperatures on varicella incidence in adults only persist for around 2 days, whereas lower temperatures have a significantly higher and longer-lasting impact on varicella incidence in children, lasting up to 10 days. These results provide valuable insights for future risk assessments of temperature-related infectious diseases and emphasize the importance of implementing targeted public health measures for vulnerable populations in relation to air temperature.

Meteorological factors, particularly air temperature, are known to influence the incidence of varicella (*1–5*). However, there is limited research on the impact of low temperature on varicella. Previous studies have suggested that relative humidity may reduce the risk of varicella incidence (*3*). The correlation between other meteorological factors such as rainfall and wind speed and varicella incidence remains unclear. Therefore, in this study, we aimed to control for confounding factors, including relative humidity, rainfall, and wind speed (*4–5*). We collected daily reported varicella cases from the Chinese infectious diseases reporting system in Jinan City from 2019 to 2021. The data were categorized by gender and age, and we identified a total of 6,528 male and 5,182 female varicella cases. Varicella cases were further classified as either adult (age ≥18 years) or child (age <18 years) (*6*), with 7,266 child cases and 4,444 adult cases reported. Additionally, we obtained daily mean temperature, relative humidity, rainfall, and windspeed data for the same period from the National Centers for Environmental Information (NCEI) website (https://www.ncei.noaa.gov/).

We employed a DLNM with a quasi-Poisson distribution to evaluate the influence of air temperature on varicella. To capture non-linear relationships between air temperature and varicella incidence, we used a natural cubic spline with 7 degrees of freedom (df). Lag effects, relative humidity, rainfall, and windspeed were modeled using 3 df each. Indicator variables were included for days of the week and holidays. We focused on a lag of 14 days to analyze the cumulative effect, lag effect, and incubation period of varicella. Specific details of the model parameters and sensitivity analyses can be found in the supplementary materials. The analysis was conducted using R software (version 4.2.2; R Foundation for

Statistical Computing, Auckland, New Zealand), utilizing the DLNM package.

The average air temperature was 13.3 ℃, with a range of −13.5 ℃ to 30.4 ℃ for air temperature, 19.7% to 97.8% for relative humidity, 0 mm to 170.6 mm for rainfall, and 2.2 m/s to 15.9 m/s for windspeed (Supplementary Table S1, available in https://weekly.chinacdc.cn/). Both higher and lower air temperatures were found to increase the risk of varicella (Figure 1). The risk of varicella gradually increased when the air temperature fell outside a certain range. The maximum relative risk (RR) for higher temperatures was 1.15 [95% confidence interval (*CI*): 1.05, 1.26] at lag 0 days, while the maximum RR for lower temperatures was 1.09 (95% *CI*: 0.84, 1.41)

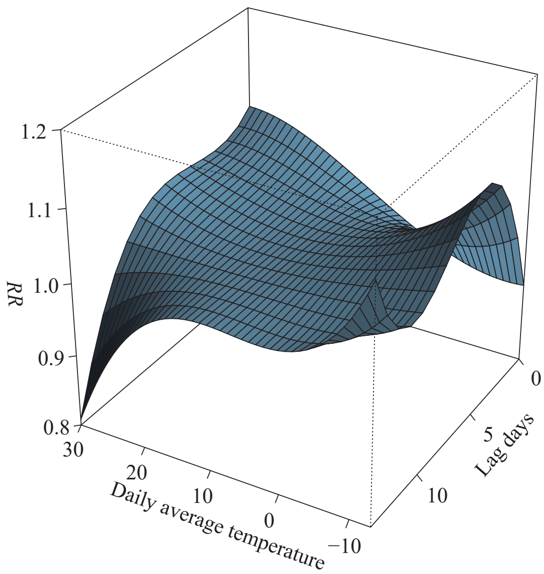

FIGURE 1. The 3D plot of the daily average temperature on varicella from 2019 to 2021 in Jinan City, Shandong Province, China.
Abbreviation: *RR*=relative risk.

at lag 14 days. The impact of lower air temperature on varicella lasted approximately 10 days, whereas the impact of higher air temperature typically only lasted around 2 days.

The influence of higher air temperature on both male and female varicella infections was found to be greater when there was a lag of 0–3 days (Figure 2). Conversely, lower air temperature had a stronger effect on varicella in males compared to females, particularly with a lag of 1–4 days. The highest RR of lower air temperature on varicella in males was 1.25 (95% *CI*: 0.79, 1.92) at a lag of 3 days, while in females it was 1.20 (95% *CI*: 0.82, 1.68) at a lag of 5 days (Figure 2).

Figure 3 illustrates that the effect of lower air temperatures on varicella in children is significantly higher compared to adults and persists for approximately 10 days. In contrast, the impact on adults only lasts for about 2 days. The maximum RR of lower air temperature on varicella in children is 1.33 (95% *CI*: 0.78, 2.30) at a lag of 4 days, while in adults it is 1.16 (95% *CI*: 0.87, 1.54) at a lag of 0 days. Additionally, the effect of higher air temperatures on varicella in both adults and children only lasts for approximately 2 days.

DISCUSSION

This study explores the relationship between air temperature and varicella incidence in Jinan from 2019 to 2021, with a focus on gender and age differences. We observed that lower air temperatures had a greater impact on varicella morbidity compared to higher air temperatures. Furthermore, there were differences in how air temperature affected varicella based on gender and age, with males and children being more vulnerable to temperature-related risks. These findings emphasize the need for targeted varicella prevention

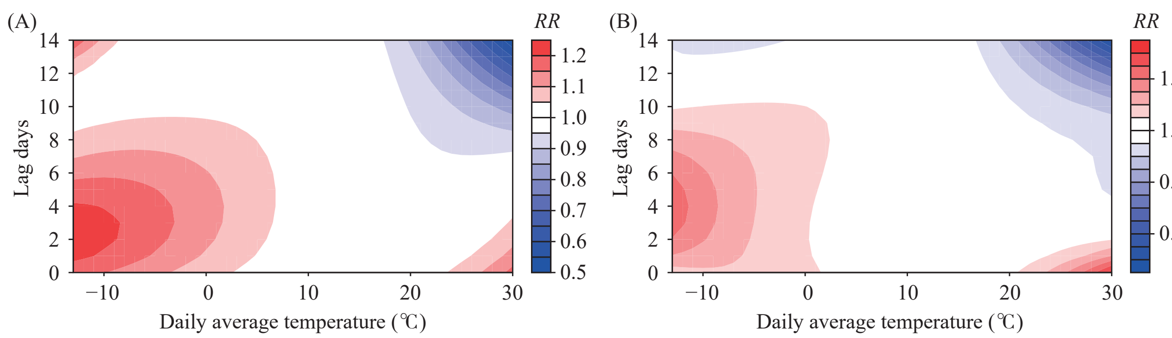

FIGURE 2. Exposure-response relationship of daily average temperature on varicella between (A) male and (B) female from 2019 to 2021 in Jinan City, Shandong Province, China.
Abbreviation: *RR*=relative risk.

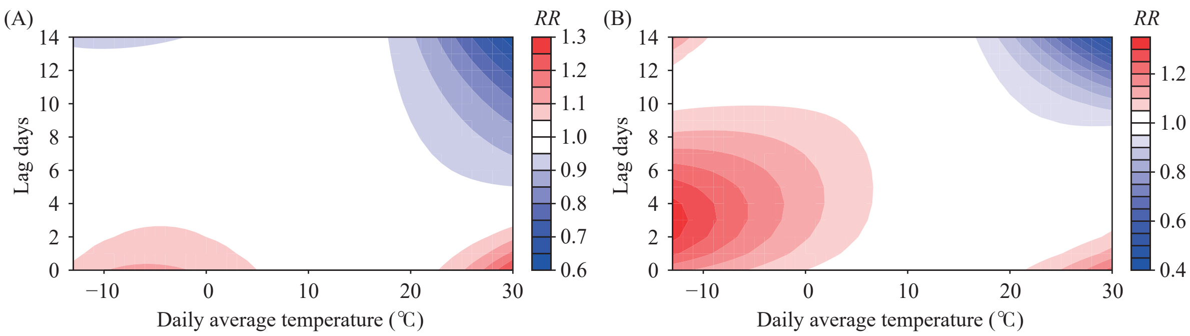

FIGURE 3. Exposure-response relationship of daily average temperature on varicella between (A) adults and (B) children of 2019 to 2021 in Jinan City, Shandong Province, China.
Abbreviation: *RR*=relative risk.

strategies for vulnerable populations based on temperature variations. For instance, a study conducted in Guangzhou found that the relative risk was highest at 1.11 (95% *CI*: 1.07, 1.16) with a 21-day lag when the mean temperature was 31.8 ℃ (*2*). On the other hand, a study in Lu'an City, Anhui Province (in eastern China) identified that the maximum single-day lag effects of varicella were 1.29 (95% *CI*: 1.20, 1.38) at a 16-day lag when the mean temperature was −5.8 ℃ (*5*). Previous studies have not consistently reported gender and age differences in temperature-related morbidity risk. Our subgroup analysis revealed that males and children were high-risk groups for temperature-related varicella, particularly in cases of lower air temperature.

There may also be differences in responses to higher air temperatures between males and females. This could be due to males engaging in more outdoor activities and being more susceptible to the impacts of higher air temperatures, while females tend to take protective measures during periods of high temperature. The greater impact of lower air temperature on varicella in males may be related to physiological factors such as body shape and hormonal influences. A study by the University of Cambridge in the UK demonstrated that in response to harsh cold environments, blood vessels in the hands and feet naturally contract to protect vital organs like the heart from inadequate blood supply (*7*). Although both males and females experience cold, females generally exhibit greater sensitivity to temperature, leading them to respond more quickly to temperature changes. Some studies have indicated an annual increase in reported varicella cases among older age groups (*8*).

Ambient temperature can directly impact biochemical reactions within the body and have direct or indirect effects on various systems. The impact of higher or lower temperatures on varicella in adults is relatively small due to their better adaptability to temperature changes. Adults tend to take effective protective measures, such as adjusting clothing and utilizing air conditioning, to mitigate the potential damage caused by temperature changes. Additionally, ambient temperature can also influence the function of the body's immune system, potentially reducing resistance to viruses and bacteria to a certain extent. However, children's physical development is not fully mature, and their regulatory mechanisms may not meet the requirements when faced with extreme temperatures (*9*).

This study has a few limitations. First, we acknowledge the presence of ecological fallacy, as it was not possible to measure individual exposure accurately. Second, limited studies have suggested that air pollution may also contribute to increased varicella incidence (*10*), which should be considered and adjusted for in future research.

In summary, we found that there are gender and age variations in the relationship between air temperature and varicella. These findings can contribute to the identification of vulnerable populations at risk of temperature-related varicella and inform the development of effective varicella control strategies.

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Corresponding author: Hongyan Yao, yaohy@chinacdc.cn.

[1] Chinese Center for Disease Control and Prevention, Beijing, China; [2] Institute for Immunization management, Shandong Center for

Disease Control and Prevention, Jinan City, Shandong Province, China; [3] State Key Laboratory of Resources and Environmental Information System, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing, China; [4] Hainan Provincial Center for Disease Control and Prevention, Haikou City, Hainan Province, China.

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REFERENCES

1. Li Y, Li J, Zhu Z, Zeng W, Zhu Q, Rong Z, et al. Exposure-response relationship between temperature, relative humidity, and varicella: a multicity study in South China. Environ Sci Pollut Res Int 2023;30(3): 7594 – 7604. http://dx.doi.org/10.1007/s11356-022-22711-8.
2. Lu JY, Zhang ZB, He Q, Ma XW, Yang ZC. Association between climatic factors and varicella incidence in Guangzhou, Southern China, 2006-2018. Sci Total Environ 2020;728:138777. http://dx.doi.org/10.1016/j.scitotenv.2020.138777.
3. Yang Y, Geng X, Liu X, Wang W, Zhang J. Association between the incidence of varicella and meteorological conditions in Jinan, Eastern China, 2012-2014. BMC Infect Dis 2016;16:179. http://dx.doi.org/10.1186/s12879-016-1507-1.
4. Hervás D, Hervás-Masip J, Nicolau A, Reina J, Hervás JA. Solar radiation and water vapor pressure to forecast chickenpox epidemics. Eur J Clin Microbiol Infect Dis 2015;34:439 – 46. http://dx.doi.org/10.1007/s10096-014-2243-3.
5. Zhang T, Qin W, Nie T, Zhang D, Wu X. Effects of meteorological factors on the incidence of varicella in Lu’an, Eastern China, 2015–2020. Environ Sci Pollut Res Int 2023;30:10052 – 62.
6. Mama RS. Needs, rights, and the human family: the practicality of the Convention on the Rights of the Child. Child Welfare 2010;89:177 – 89.
7. Bain AR, Ainslie PN, Bammert TD, Hijmans JG, Sekhon M, Hoiland RL, et al. Passive heat stress reduces circulating endothelial and platelet microparticles. Exp Physiol 2017;102:663 – 9.
8. Fu J, Jiang C, Wang J, Zhao F, Ma T, Shi R, et al. Epidemiology of varicella in Haidian district, Beijing, China-2007–2015. Vaccine 2017;35:2365 – 71.
9. Leyk D, Hoitz J, Becker C, Glitz KJ, Nestler K, Piekarski C. Health Risks and Interventions in Exertional Heat Stress. Dtsch Arztebl Int 2019;116:537 – 44.
10. Wang Z, Li X, Hu P, Li S, Guan J, Wang B, et al. Influence of air pollutants on varicella among adults. Sci Rep 2021;11(1):21020. http://dx.doi.org/10.1038/s41598-021-00507-z.

SUPPLEMENTARY MATERIAL

Model Parameters

The formula is shown below (*1*):

$$Yt \sim QuasiPoisson(\mu t)$$

$$\log(\mu t) = \alpha + \mathrm{NS}(\mathrm{Time}, T \times 7) + \mathrm{NS}(\mathrm{Humidity}, 3) + \mathrm{NS}(\mathrm{Rainfall}, 3) + \mathrm{NS}(\mathrm{Windspeed}, 3) + \gamma \mathrm{Dow} + \eta \mathrm{Holiday} + \beta \mathrm{Temperature}$$

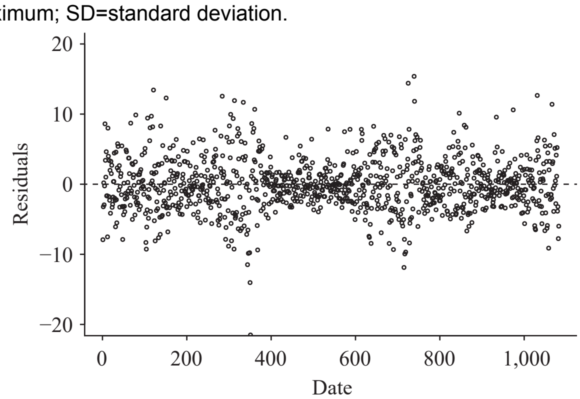
In the formula, the variable Yt represents the daily number of varicella cases at a given time t. The intercept is represented by α, and there are coefficients γ, η, and β. Time is a time trend variable, and a natural cubic spline curve was used to model it. We controlled for the long-term trend and seasonality effects using NS (Time). We also controlled for the effects of relative humidity using NS (Humidity), the effects of rainfall using NS (Rainfall), and the effects of windspeed using NS (Windspeed). Additionally, Dow represents the day of the week, indicating the presence of a weekend effect, and Holiday represents public holidays, indicating the presence of a holiday effect.

This study aimed to assess the relationship between daily average temperature and daily varicella incidence. Previous studies have shown a decreased risk of varicella with higher relative humidity (*2*–*3*). However, the correlation between meteorological factors and varicella incidence, particularly rainfall and wind speed, remains unclear. Furthermore, the impact of rainfall on varicella incidence has shown significant variation (*4*–*5*). Therefore, this study sought to account for potential confounding factors, including relative humidity, rainfall, and wind speed, in order to obtain accurate research results.

SUPPLEMENTARY TABLE S1. Descriptive data on daily varicella incidence and weather conditions in Jinan City, Shandong Province, China, 2019–2021.

Variables	Min	Median	Max	Mean	SD
Mean temperature (℃)	−13.5	13.8	30.4	13.3	10.0
Relative humidity (%)	19.7	58.8	97.8	59.3	17.2
Rainfall (mm)	0	0	170.6	2.2	8.9
Windspeed (m/s)	2.2	5.5	15.9	5.8	1.9
Cases					
Total	0	9	50	10.7	7.7
Male	0	5	26	6	4.7
Female	0	4	26	4.7	3.7
Child	0	5	31	6.6	5.6
Adult	0	3	19	4.1	3.2

Abbreviation: Min=minimum; Max=maximum; SD=standard deviation.



SUPPLEMENTARY FIGURE S1. Sensitivity analyses of the distributed lag non-linear model from 2019 to 2021 in Jinan City, Shandong Province, China.

Notes: Residuals were symmetrically distributed above and below 0. By changing parameters such as the maximum lag and degrees of freedom (df) of long-term trends, it was found that the model fitting results showed no significant fluctuations, indicating the overall stability of the model. It was proven that our model was stable and could be applied.

REFERENCES

1. Gasparrini A. Distributed lag linear and non-linear models in R: the package dlnm. J Stat Softw 2011;43:1-20. https://pubmed.ncbi.nlm.nih.gov/22003319/.
2. Chan JY, Tian LW, Kwan Y, Chan W, Leung C. Hospitalizations for varicella in children and adolescents in a referral hospital in Hong Kong, 2004 to 2008: a time series study. BMC Public Health 2011;11:366. http://dx.doi.org/10.1186/1471-2458-11-366.
3. Yang YQ, Geng XY, Liu XX, Wang WR, Zhang J. Association between the incidence of varicella and meteorological conditions in Jinan, eastern China, 2012-2014. BMC Infect Dis 2016;16:179. http://dx.doi.org/10.1186/s12879-016-1507-1.
4. Hervás D, Hervás-Masip J, Nicolau A, Reina J, Hervás JA. Solar radiation and water vapor pressure to forecast chickenpox epidemics. Eur J Clin Microbiol Infect Dis 2015;34(3):439 – 46. http://dx.doi.org/10.1007/s10096-014-2243-3.
5. Harigane K, Sumi A, Mise K, Kobayashi N. The role of temperature in reported chickenpox cases from 2000 to 2011 in Japan. Epidemiol Infect 2015;143(12):2666 – 78. http://dx.doi.org/10.1017/S095026881400363X.