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The effects of summer temperature and heat waves on heat-related illness in a coastal city of China, 2011–2013

Li Bai [a,1], Gangqiang Ding [b,1], Shaohua Gu [a], Peng Bi [c], Buda Su [d], Dahe Qin [d], Guozhang Xu [e,**], Qiyong Liu [a,f,g,*]

[a] State Key Laboratory for Infectious Diseases Prevention and Control, National Institute for Communicable Disease Control and Prevention, Chinese Center for Disease Control and Prevention, 155 Changbai Road, Changping District, Beijing 102206, China
[b] Zhejiang Provincial Center for Disease Control and Prevention, Hangzhou 310051, China
[c] School of Population Health, University of Adelaide, South Australia 5005, Australia
[d] National Climate Center, Beijing 100081, China
[e] Ningbo Center for Disease Control and Prevention, Ningbo 315010, China
[f] Shandong University Climate Change and Health Center, Jinan 250100, China
[g] Collaborative Innovation Center for Diagnosis and Treatment of Infectious Diseases, Hangzhou 310003, China

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ABSTRACT

Background: Devastating health effects from recent heat waves in China have highlighted the importance of understanding health consequences from extreme heat stress. Despite the increasing mortality from extreme heat, very limited studies have quantified the effects of summer extreme temperature on heat-related illnesses in China.

Methods: The associations between extreme heat and daily heat-related illnesses that occurred in the summers of 2011–2013 in Ningbo, China, have been examined, using a distributed lag non-linear model (DLNM) based on 3862 cases. The excess morbidities of heat-related illness during each heat wave have been calculated separately and the cumulative heat wave effects on age-, sex-, and cause-specific illnesses in each year along lags have been estimated as well.

Results: After controlling the effect of relative humidity, it is found that maximum temperature, rather than heat index, was a better predictor of heat-related illnesses in summers. A positive association between maximum temperatures and occurrence of heat-related diseases was apparent, especially at short lag effects. Six heat waves during the period of 2011–2013 were identified and all associated with excess heat-related illnesses. Relative to the average values for the corresponding periods in 2011 and 2012, a total estimated 679 extra heat-related illnesses occurred during three heat waves in 2013. The significant prolonged heat wave effects on total heat-related illnesses during heat waves in three study years have also been identified. The strongest cumulative effect of heat waves was on severe heat diseases in 2013, with a 10-fold increased risk. More males than females, individuals with more severe forms of illness, were more affected by the heat. However, all age groups were vulnerable.

Conclusions: Recent heat waves had a substantial and delayed effect on heat illnesses in Ningbo. Relevant active well-organized public health initiatives should be implemented to reduce the adverse effects of heat extremes on the illnesses.

1. Introduction

Extreme weather events including extreme heat are dramatically challenging population health and safety in China. Although the Chinese Government has made increasing efforts to address the impact of climate change, it appears that the health implications have received less attention, comparing with the energy, economic and agriculture sectors. It is therefore very important for public health professionals to understand the patterns of health effects during extreme weather events and then to assist

* Corresponding author at : State Key Laboratory for Infectious Diseases Prevention and Control, National Institute for Communicable Disease Control and Prevention, Chinese Center for Disease Control and Prevention, 155 Changbai Road, Changping District, Beijing 102206, China. Fax: +86 10 58900739..
** Co-corresponding author.
E-mail addresses: baili_ChinaCDC@163.com (L. Bai), gqding@cdc.zj.cn (G. Ding), gushaohua1989@sina.com (S. Gu), peng.bi@adelaide.edu.au (P. Bi), subd@cma.gov.cn (B. Su), qdh@cma.gov.cn (D. Qin), xugz@nbcdc.org.cn (G. Xu), liuqiyong@icdc.cn (Q. Liu).
[1] These authors contributed equally to this manuscript.

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stakeholders for their decision-makings and service guideline implementation.

Both single days with extreme high temperatures and prolonged heat waves can affect human health (Anderson and Bell, 2011). Increased mortality and morbidity associated with extreme heat have also been observed worldwide (Lindstrom et al., 2013; Lowe et al., 2011; Rocklov and Forsberg, 2008; Toloo et al., 2013, Williams et al., 2012) and parts of China (Chen et al.,2013; Goggins et al., 2012; Guo et al., 2011; Kan et al., 2003; Tian et al., 2012; Wu et al., 2013; Yang et al., 2013), and attributed mainly to diseases of the cardiovascular and respiratory systems, especially among the elderly. Most of such studies used an ultimate health index, mortality, as a health indicator.

However, there are limited studies examining the relationship between extreme heat and direct heat-related illnesses, and little is known about the pattern of population vulnerability of this type of illness in China. Excessive heat can suddenly become life threatening, especially among people with severe heat stroke symptoms. Once core body temperature reaches 40 °C, cellular damage occurs rapidly, initiating a cascade of events that may lead to organ failure and possible fatality (Becker and Stewart, 2011). Heat-related illnesses can also exacerbate existing medical conditions and this makes the elderly more likely to be affected. In the United States, hyperthermia was recorded as a contributing cause of death increased by 54% of the total number of heat-related deaths during 1999–2003 (CDC, 2006). Furthermore, Korea experienced the hottest summer in 2012 over the past ten years, with 975 heat-related illness (with 78.5% cases occurred outdoors) being reported nationally (Na et al., 2013).

Given that more intense, frequent, and longer heat durations are projected (IPCC, 2011), understanding how heat stress affects heat-related illness and the population at risks is crucial to plan and implement relevant public health intervention programs. In this study, we estimated the relationships between summer maximum temperature and daily heat-related illnesses in a coastal city of Ningbo, China.

2. Methods

2.1. Study settings and data sources

The city of Ningbo, is located on the eastern coast of China and is one of the most important and busiest port cities, second only to Shanghai. In 2010, the population of the city was 7,605,689 (51.1% men; 48.9% women). The city has a humid subtropical climate with four distinctive seasons, characterized by long, hot, humid summers and chilly, cloudy winters. Due to the effects of the subtropical high over the Pacific, Ningbo always experiences longer periods of extreme heat during the summer. In the summer of 2013, maximum temperatures exceeding 40 °C occurred on 11 days.

Since 2007, the Chinese Center of Diseases Control and Prevention (China CDC) has operated a national heat-related illness surveillance system. Local medical institutions (including hospitals, ambulance centers and community health centers etc.) in each city are required to collect the information from patients who were diagnosed with heat-related symptoms due to exposure to extreme high temperatures in summers. The CDC of Ningbo then collected daily cases from all medical institutions through the electronic surveillance system daily. Items to be reported include diagnosis, date of onset, outcome of treatment and patient's age, sex, and residential street address. Diagnosis is categorized into mild and severe heat-related illness according to uniform criteria across all surveillance cities (Table 1).

The collected data of daily heat-related illness from this surveillance system for Ningbo city covered the summers of 2008–2013. However, only the data from 2011 to 2013 were used for analysis, because of apparent underreporting and a large number of missing information of patients from the early stage of the surveillance system between 2008 and 2010. The data were then reclassified by sex, age groups (0–15 y, 16–44 y, 45–64 y and 65 or older) and forms of heat-related illness (mild and severe). Meteorological data on daily mean, minimum and maximum temperatures and relative humidity in Ningbo during the same period were provided by the China National Climate Center. The data of air pollution were not included in the analysis, since they were not available during the study period.

2.2. Data analysis

2.2.1. The relationships between extreme heat and heat-related illnesses

After data clean and collation, a distributed lag non-linear model (DLNM) (Gasparrini, 2011; Gasparrini et al., 2010) was used to examine the relationship between summer maximum temperature and daily heat-related illness during June–August from 2011 to 2013. DLNM has recently been applied in studies to quantify the effects of temperature (Guo et al., 2011; Kim et al., 2012; Lin et al., 2013) and air pollution (Goldberg et al., 2013) on human health. The major advantage of this model is that it is flexible to simultaneously describe a non-linear exposure–response association and lagged or harvesting effects (Gasparrini, 2011; Gasparrini et al., 2010). Long-term trends were controlled using a natural cubic spline with 7 *df* per year for time and relative humidity which was adjusted using a natural cubic splines with 3*df*. To control any confounding by weekly pattern, day of week (DOW) was also included as an indicator in the analysis. Public holiday was controlled as a binary variable.

A DLNM with 4 degrees of freedom natural cubic for temperature (knots at equally-spaced percentiles by default) and with 4 degrees of freedom natural cubic for lagged effects (knots at equally-spaced values in the log scale of lags by default) were used in the analysis. The median value of summer maximum temperature was used as the reference value. The effects on total heat-related illness for lags 0, 1 and 2 days were examined and plotted.

As an alternative temperature indicator, the heat index was also used to examine its effects on heat-related illness by DLNM. The heat index in Fahrenheit was firstly calculated based on maximum temperature (°F) and relative humidity using a formula developed by the US National Weather Service (Rothfusz, 1990) and then converted to Celsius. Natural cubic spline with 4 *df* was applied in the daily heat index. The Akaike's Information Criterion for quasi-Poisson (Q-AIC) which uses deviance as a measure of fit was applied to verify the optimal *df* of models, using maximum temperature and heat index to find out which one can best predict the incidence of patients with heat-related illness.

2.2.2. Effects of heat waves on heat-related illness

The Chinese National Bureau of Meteorology defines a “heat day” as a day with daily maximum temperature exceeding 35 °C. In this study, a heat wave was defined as ≥ 7 consecutive heat days with the maximum temperature over 35 °C. Similar definitions have been applied in previous studies in similar settings with Ningbo, such as Shanghai and Guangzhou (Ma et al., 2011; Yang et al., 2013). According to this definition, six heat waves were identified during 2011–2013 in Ningbo (Table 2).

In order to examine excess morbidity of heat-related illness during each heat wave, the 31-day moving average values (15 days on either side of the index day) for daily counts of heat-related illness were calculated for individual year, and 2011 and 2012 combined (Rooney et al., 1998). Excess morbidity in each heat wave was assessed as the difference between the numbers of heat-related illness observed on

Table 1
Diagnosis of heat-related illness.

Type		Characteristics and symptoms
Mild illness		Dizziness, headache, flushing, thirst, sweating a lot, weakness, palpitation, rapid pulse, attention-deficit, loss of coordination, body temperature $\geq$ 38.5 °C.
Severe illness	Heat stroke	Happen suddenly in hot environment, sweating occurs at first and then stops with hot and dry skin, disturbance of consciousness, body temperature $\geq$ 40 °C.
	Heat cramp	Muscle spasms with pains, usually in the calves, arms, abdominal wall and back, clear consciousness, normal body temperature.
	Heat exhaustion	Happen suddenly, dizziness, headache, sweating a lot, thirst, nausea, vomiting, moist and cool skin, drop in blood pressure, tachycardia, mild dehydration, normal or slightly high body temperature.