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

Li Bai, Gangqiang Ding, Shaohua Gu, Peng Bi, Buda Su, Dahe Qin, Guozhang Xu, Qiyong Liu

*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

†Zhejiang Provincial Center for Disease Control and Prevention, Hangzhou 310051, China

‡School of Population Health, University of Adelaide, South Australia 5005, Australia

§National Climate Center, Beijing 100081, China

© Ningbo Center for Disease Control and Prevention, Ningbo 315010, China

†Shandong University Climate Change and Health Center, Jinan 250100, China

†Collaborative Innovation Center for Diagnosis and Treatment of Infectious Diseases, Hangzhou 310003, China

**Corresponding author.
E-mail addresses: bail.ChinaCDC@163.com (L. Bai), gdqding@cdc.zj.cn (G. Ding), gushaohua1989@sina.com (S. Gu), peng.bi@adelaide.edu.au (P. Bi), subd@cma.gov.cn (B. Su), qldb@cma.gov.cn (D. Qin), xugz@nbcdc.org.cn (G. Xu), liuqiyong@icdc.cn (Q. Liu).

1 These authors contributed equally to this manuscript.

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...
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; Toolo 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 (31.1% 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. Locations are aggregated 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) (Gasparini, 2011; Gasparini 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 (Gasparini, 2011; Gasparini 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 (Rebichuz, 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.

<table>
<thead>
<tr>
<th>Type</th>
<th>Characteristics and symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild illness</td>
<td>Dizziness, headache, flushing, thirst, sweating a lot, weakness, palpitation, rapid pulse, attention-deficit, loss of coordination, body temperature ≥ 38.5 °C.</td>
</tr>
</tbody>
</table>
| 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 ≥ 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. |
3. Results

Overall a total number of 3862 heat-related illnesses were included during June–August over the period 2011–2013 (Table 2), with more males than females being affected. Those who are 65 or older account for 11.6% of the total illnesses. The percentage of patients with mild heat-related illnesses were much higher than those with severe conditions including heat stroke, heat cramps and heat exhaustion (92.1% vs 7.9%). The mean maximum temperature and relative humidity in Ningbo during the study period were 32.8 °C and 74.5% respectively.

Fig. 1 shows the relationship between daily heat-related illnesses and maximum temperature during June–August in 2011–2013. In general, more cases (69.6%) occurred on days with maximum temperature higher than 35 °C. Relative to 2011–2012, temperatures in 2013 were on average 3 °C higher during the period June–August, and more cases were also reported in this year.

Effects of maximum temperatures (with control of relative humidity) and heat index on total heat-related illness during June–August from 2011 to 2013 at lags 0,1 and 2 were plotted respectively (Fig. 2). The daily maximum temperature is found to be a better predictor (having a lower Q-AIC value of 1902.16) than the maximum heat index. A positive association between maximum temperatures and occurrence of heat-related diseases was apparent. The effects by using both temperature indicators were largest at lag 0 and then decreased rapidly.

Tables 3 and 4 summarized characteristics of each heat wave in summers from 2011 to 2013 and total and excess illnesses during heat waves by age, sex and type of heat-related illnesses. Since higher temperatures and more cases were observed in 2013, we also estimated excess deaths during heat waves in 2013 compared with the corresponding moving average values for 2011 and 2012 combined (Table 5). Overall six heat waves during the study period were identified (two in 2011, one in 2012 and three in 2013). The median values of maximum temperature during heat waves ranged from 35.5 to 39.6 °C.

Based on comparison with the same year, the effect on heat-related illnesses was greatest during the first heat wave in 2011, with a 123.4% increase. Regarding the timing of heat waves, it was also found that the heat waves in early July led to higher excess illnesses. The increase in illnesses tended to be more noticeable among males, those aged 0–15 years and the elderly, although the effects were not consistent during each heat wave. The effects were also more pronounced for severe heat-related conditions than mild ones.

Relative to the average values for the corresponding periods in 2011 and 2012, a total estimated 679 extra illnesses occurred during three heat waves in 2013. The worst heat wave was the third one in August, 2013, with a duration of 15 consecutive days over 35 °C and an extreme maximum temperature of 42.1 °C. This led to a 168.8% increase in heat-related illness. The effects were severe for males, the elderly, while those aged 0–15 tended to be less affected based on the comparison with the effects of 2011 and 2012 combined heat waves. The stronger heat waves were also observed to have more effects on the people with severe heat illnesses rather than these with mild ones.

The heat wave effects along lags on heat-related illnesses by age, sex and type were calculated along the lags in 2011–2013 (Table 5). There were significant increases in total heat-related illnesses during heat waves over three study years. However, the strongest cumulative effect of heat waves on severe heat diseases was observed in 2013, with a 10-fold increased risk. For all three years, the estimated risk associated with heat waves was higher for severe illnesses than that for mild conditions and for males than for females except for cumulative effects in 2012. The effects by age groups were less consistent across three years. In 2011, the most affected groups were those aged 0–15 years, while middle aged populations and the elderly were at higher risks of having heat-related conditions in 2012 and 2013 respectively.

4. Discussion

This is the first study assessing the effects of summer temperatures and heat waves on direct heat-related illnesses and identifying vulnerable subpopulations in China, using Ningbo as a study location.
There was a clear positive relationship between summer high temperatures and acute occurrences of heat-related illnesses with no lagged effect. Each heat wave during three summers in study years was associated with an estimated excess of total heat-related illnesses over the average for the same year. The effects of the heat waves generally lasted five days and lead to significant increased risks of the development of heat illnesses. Males, children and the elderly tended to be at higher risks during heat exposures. Heat waves had a much greater impact on severe heat conditions than mild heat symptoms.

Health impacts caused by extreme high temperatures in summers were widely assessed by examining heat effects on mortality and morbidity worldwide, targeting on cardiovascular, renal and mental health diseases (Hansen et al., 2008a, 2008b, Chan et al., 2013; Guo et al., 2012; Tian et al., 2012; Wichmann et al., 2011; Zanobetti et al., 2013; Zhang et al., 2013). Little is known about direct effects of excess heat on acute heat-related illnesses, particularly potentially fatal heat-related illnesses. Reductions in summer direct illness and deaths due to extreme heat might have many challenges such as warming temperatures, aging population, and increasing prevalence of chronic diseases. In New York, there were approximately 600 cases of serious illness and 13 deaths annually as a result of heat-related illnesses during 2000–2011 (CDC, 2013). In a study in Korea, the estimated relative risks of the total patient incidence of heat-related illnesses during the summer of 2012 was 1.691 (1.641–1.743) per 1 °C increase after 32.1 °C (Na et al., 2013). The study also found that the daily maximum temperature showed the better goodness of fit with the model than heat index did, which is consistent with our findings in the current study.

Compared with average illnesses for 2011 and 2012, there was a significant increase in excess direct heat-related illnesses (with 679 extra cases) during three strong heat waves in 2013, and had severe consequences with heat-related illnesses including heat stroke, heat cramps and heat exhaustions. The second and third heat waves in 2013 happened two days apart, which would have had a much bigger impact on heat-related illnesses because of the severity and duration, especially for vulnerable groups. This suggests relevant preventative measurements targeting on vulnerable people. Furthermore, further impact assessments are needed if the two heat waves are combined into one extreme heat event.

During July–mid-August 2013, longer and hotter heat waves affected many Provinces of China, breaking daily temperature records in many cities including Ningbo. On 30 July, 2013, The China Meteorological Administration (CMA) issued the very first Severe Meteorological Disaster Emergency Response Warning based on the II-level heat alarm which indicates maximum temperatures in following 3 days or more would exceed 40 °C in most of regions; human health would be severely threatened; daily routine activities would be dramatically affected; electricity demands within a city would increase sharply; and the frequency of restriction of electricity use would rise significantly. The Ningbo

Fig. 1. Maximum temperature and heat-related illness in 2011 (upper), 2012 (middle) and 2013 (lower) during June–August.
Meteorological Administration also issued highest alerts for heat from 24 July to 7 August 2013 and started the highest level of meteorological disaster emergency response mechanisms. A collaborative mechanism across multi-sectors and institutions was operated to better monitor weather conditions and heat illnesses, and take actions to protect local communities from the adverse impacts of extreme heat. For example, heat alerts and information about preventing and coping acute heat-related diseases were dynamically issued everyday via websites, blogs, mobile phones, newspapers, radio, televisions etc. Batches of artificial rainfall were implemented during heat waves to cope with droughts due to long lasting extreme heats and very low precipitations.

*Fig. 2.* Dose–response relationship using maximum temperature (left) and heat index (right) with the lagged effects. The reference values are median values of maximum temperature (33.5 °C) and heat index (46.1 °C) during June–August from 2011 to 2013.
According to previous evidence, children and the elderly are mostly vulnerable to high temperature in summers, with the highest rates of heat-related illness and death. However, in this study, we highlighted that people of all ages are at risks of heat-related diseases during heat waves. Young adults may be equally vulnerable, as they may be exposed more frequently outdoors to heat and affected by chronic physical and mental health conditions. Unlike most of previous studies which reported that females are at higher risks of dying or being sick during heat events (Na et al., 2013; Stafoggia et al., 2006; Vanekova et al., 2008; Yu et al., 2010), we found that males than females were more likely to suffer from heat-related illnesses in Ningbo. This is perhaps explained by the fact that men are far more likely to engage in outdoors strenuous activities or works than women during heat waves. In high ambient temperatures, their health are seriously threatened.

Severe heat-related illnesses including heat strokes were found to be more affected by heat waves than mild forms in this study. This is similar with a previous work which reported that the relative risks of heat strokes were significantly higher than those of other illness types during high temperature days (Na et al., 2013). Heat stroke is a true immediate medical emergency. If milder heat symptoms are left untreated or improper treatment was taken, fatalities associated with hyperthermia can develop. Rapid diagnosis including early recognition of at-most-risk groups can help to best target heat emergency response activities and local-specific prevention efforts. We therefore suggest that the current surveillance system should be improved with collections of more comprehensive patients’ information during diagnosis or treatment, which includes occupation, chronic conditions, mental health status, medication use, place where the heat-related symptoms occur, living conditions, access to air-conditioning etc.

### Table 3
Total and excess heat-related illness during each heat waves from 2011 to 2012.

<table>
<thead>
<tr>
<th>Observed cases</th>
<th>Excess cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>%</td>
</tr>
<tr>
<td><strong>Year: 2011</strong></td>
<td></td>
</tr>
<tr>
<td>1st</td>
<td>Compared with 2011</td>
</tr>
<tr>
<td>Period: 1–8 July</td>
<td>All</td>
</tr>
<tr>
<td>Duration (d): 8</td>
<td>0–15 y</td>
</tr>
<tr>
<td>Max temperature (°C)</td>
<td>16–44 y</td>
</tr>
<tr>
<td>Min: 35.2</td>
<td>45–64 y</td>
</tr>
<tr>
<td>Median: 36.9</td>
<td>65 y</td>
</tr>
<tr>
<td>Max: 38.8</td>
<td>Male</td>
</tr>
<tr>
<td>Median RH (%)</td>
<td>38.5</td>
</tr>
<tr>
<td>Median HI (%)</td>
<td>59.0</td>
</tr>
<tr>
<td></td>
<td>Severe</td>
</tr>
<tr>
<td>2nd</td>
<td>Period: 20–26 July</td>
</tr>
<tr>
<td>Duration (d): 7</td>
<td>0–15 y</td>
</tr>
<tr>
<td>Max temperature (°C)</td>
<td>16–44 y</td>
</tr>
<tr>
<td>Min: 35.0</td>
<td>45–64 y</td>
</tr>
<tr>
<td>Median: 35.5</td>
<td>65 y</td>
</tr>
<tr>
<td>Max: 36.7</td>
<td>Male</td>
</tr>
<tr>
<td>Median RH (%)</td>
<td>75.0</td>
</tr>
<tr>
<td>Median HI (%)</td>
<td>56.1</td>
</tr>
<tr>
<td></td>
<td>Severe</td>
</tr>
<tr>
<td><strong>Year: 2012</strong></td>
<td></td>
</tr>
<tr>
<td>1st</td>
<td>Period: 30 June–14 July</td>
</tr>
<tr>
<td>Duration (d): 15</td>
<td>0–15 y</td>
</tr>
<tr>
<td>Max temperature (°C)</td>
<td>16–44 y</td>
</tr>
<tr>
<td>Min: 35.2</td>
<td>45–64 y</td>
</tr>
<tr>
<td>Median: 37.1</td>
<td>65 y</td>
</tr>
<tr>
<td>Max: 39.0</td>
<td>Male</td>
</tr>
<tr>
<td>Median RH (%)</td>
<td>75.0</td>
</tr>
<tr>
<td>Median HI (%)</td>
<td>56.9</td>
</tr>
<tr>
<td></td>
<td>Severe</td>
</tr>
</tbody>
</table>

### Table 4
Total and excess heat-related illness during each heat waves in 2013 compared with the corresponding average values for 2013 and 2011–2012 combined.

<table>
<thead>
<tr>
<th>Observed cases</th>
<th>Excess cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>%</td>
</tr>
<tr>
<td><strong>Year: 2013</strong></td>
<td></td>
</tr>
<tr>
<td>1st</td>
<td>Period: 1–11 July</td>
</tr>
<tr>
<td>Duration (d): 11</td>
<td>Male</td>
</tr>
<tr>
<td>Max temperature (°C)</td>
<td>Female</td>
</tr>
<tr>
<td>Min: 35.5</td>
<td>0–15 y</td>
</tr>
<tr>
<td>Median: 37.1</td>
<td>16–44 y</td>
</tr>
<tr>
<td>Max: 42.1</td>
<td>45–64 y</td>
</tr>
<tr>
<td>Median RH (%)</td>
<td>64</td>
</tr>
<tr>
<td>Median HI (%)</td>
<td>52.2</td>
</tr>
</tbody>
</table>

### footnotes

- a RH: relative humidity.
- b HI: heat index.
Proper adaptation actions before and during extreme heat can make heat illness preventable. Accurate heat alerts that precipitate heat-related illnesses can better assist public health systems to take the necessary actions and precautions. Medical institutions and emergency centers should be more prepared before heat events with ample medical resources such as intravenous fluids, oxygen and extra beds for rapid treatment. Rapid access to cooling places is the most effective way to prevent the development of fatal heat-related illnesses (Smith, 2005). Cooling centers could be built in those locations or communities with less access to air-conditioning. Other air-conditioned public places and swimming pools can be also provided. Community staff and public health professionals can work together to identify those at highest risk such as the elderly, those living alone with chronic disease or physical disabilities and having no access to air-conditioning, and make cool places available to them. Risk communication is critical. Guides to preparing for and coping the heat should be easily accessible for the public, particularly for those who are unable to use a computer to obtain detailed information. Finally, massive outdoor events or activities during heat waves should be rescheduled (Becker and Stewart, 2011).

Our findings in this study will provide a significant implication to (1) policy-makers for their decision making process, in health and other sectors including industry, emergency response, build and construction departments etc., especially when the government wants to establish heat and health early warning systems, (2) service providers for the development and implementation of their service guidelines such as aged cared industries, emergency departments of hospitals, ambulance services, as well as unions etc., (3) community staff and public health professionals to conduct community health education and health promotion campaigns including neighbor watch programs during extreme heat, and (4) the individuals for behavior modifications such as drinking more fluids, wearing light clothing, avoiding outdoor activities, using a home air-conditioner or seeking an air-conditioned location etc.

Several limitations of the study should be noted. Firstly, under-reporting of heat-related diseases exists, as some people with milder symptoms related to heat exposure may not go to see a doctor and therefore cannot be reported. This means that the impacts of extreme heat on this type of diseases may be underestimated. Moreover, there is a possibility of inaccurate diagnosis of heat-related cases. Although medical institutions are required to use the same national criteria to diagnose, differences among physicians’ individual experiences may lead to misclassification of heat conditions. Due to minor differences between definitions of mild and severe heat illnesses, physicians may also misclassify the two forms of illnesses. Besides, using data of heat-related illness reporting of heat-related diseases exists, as some people with potential over-reported bias over time. In addition, with this study design it was not possible to control other time-varying confounding variables such as intake of alcohol, smoking rates, and use of medications. Finally, air pollution data were not available from Ningbo over the study period, which varies over short periods of time, and may modify the temperature–morbidity relationship.

5. Conclusion

This study analyzed the effects of temperature and heat waves on heat-related illnesses occurring June–August from 2011 to 2013 in a Chinese context. We found that heat waves dramatically
increased morbidity of heat-related illnesses in Ningbo city. We also observed that the heat wave effect was much stronger for severe heat-related illnesses than mild ones. Males were at higher risks of having heat-related conditions during heat waves than females, and all age groups were at risks in terms of heat diseases. Although a series of actions have been conducted in Ningbo, there are still many spaces and opportunities in dealing with health effects of extreme temperatures and particular attention should be paid to groups at greater risk. Further studies are required to better learn local-specific vulnerability pattern and implement more specific interventions.

Ethical approval

We obtained ethical approval from the Ethical Review Committee of Chinese Center for Disease Control and Prevention for this study (No. 201214).

Competing interests

The authors declare that they have no competing interests.

Acknowledgments

This study was supported by the National Basic Research Program of China (973 Program) (Grant no. 2012CB955504).

References