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

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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

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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 ≥ 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 ≥ 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.

Table 2
Summary statistics of weather and demographic characteristics of patients in Ningbo during June–August, 2011–2013.

Maximum temperature	**°C**
Mean (SD[a])	32.8 (4.4)
Min	19.9
25th	29.7
Median	33.5
75th	35.8
Max	42.1
Relative humidity	**%**
Mean (SD[a])	74.5 (9.9)
Min	49
25th	67
Median	75
75th	83
Max	95
Patients under study	***n* (%)**
Sex	
Male	2242 (58.1)
Female	1620 (41.9)
Age	
0–15	214 (5.5)
16–44	1919 (49.7)
45–64	1282 (33.2)
≥ 65	447 (11.6)
Heat-related illness	
Mild	3557 (92.1)
Severe[b]	305 (7.9)
Total cases	**3862**

[a] Standard deviation.
[b] Severe heat-related illness includes heat stroke, heat cramp and heat exhaustion.

a given day and the corresponding moving average, for 2011–2013. This method is considered to be preferred and more conservative for excess mortality estimate, as the values for heat wave days are included in the average values (Rooney et al., 1998). The excess morbidity, during 2013 heat waves based on comparison with 2011 and 2012 combined, was also estimated, as the summer in 2013 was the hottest summer in Ningbo in recent years.

DLNMs were then applied to examine the effect of heat waves in 2011–2013 separately on heat-related illness by age, sex and types. A binary variable that equals 1 for heat wave days and 0 otherwise was modeled in the analysis. A lag of 5 days was used to capture the short-term heat wave effect, and a third-degree polynomial was employed to gain more precision in the estimate of distributed lag pattern (Xie et al., 2013). The cumulative effects of heat-related illness associated with heat waves in each year were estimated by treating the "crossbasis functions" for the spaces of the dimensions of the heat wave and lags as a covariate in the Poisson regression. Factors including relative humidity, time, day of the week, and public holiday were also introduced into the models as confounders. Results are expressed as Relative Risks (RRs) with 95% confidence intervals (CIs).

Sensitivity analysis were conducted by varying the *df* for time from 5 to 12 per year, the maximum lag days from 2 to 10 days, and the *df* for temperature, heat index and lags from 3 to 6. The Q-AIC was used to judge the optimal degrees of freedom. All statistical tests and modeling were performed using the R software (version 3.0.1). Distributed lag non-linear models were fitted through "dlnm" package (Gasparrini, 2011). The ethical approval was obtained from the Ethical Review Committee of Chinese Center for Disease Control and Prevention for this study (No. 201214).

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 4). 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

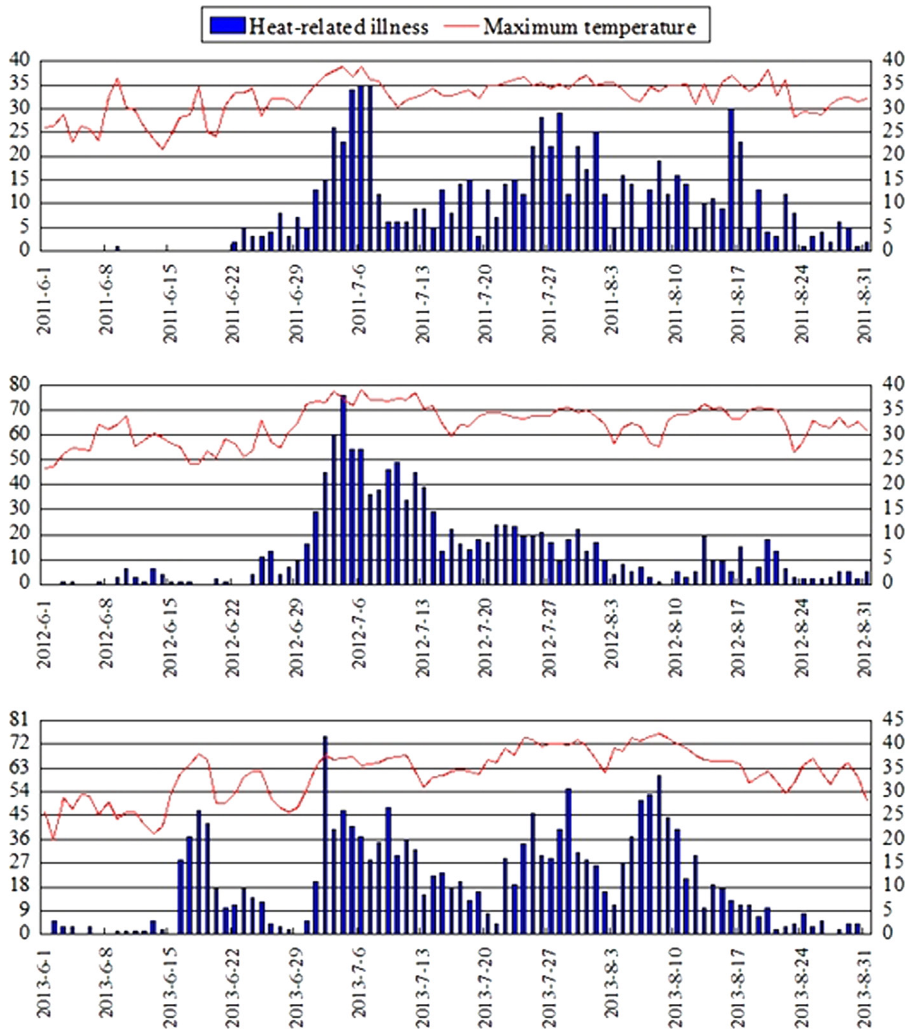

Fig. 1. Maximum temperature and heat-related illness in 2011 (upper), 2012 (middle) and 2013 (lower) during June–August.

city from 2011 to 2013. 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

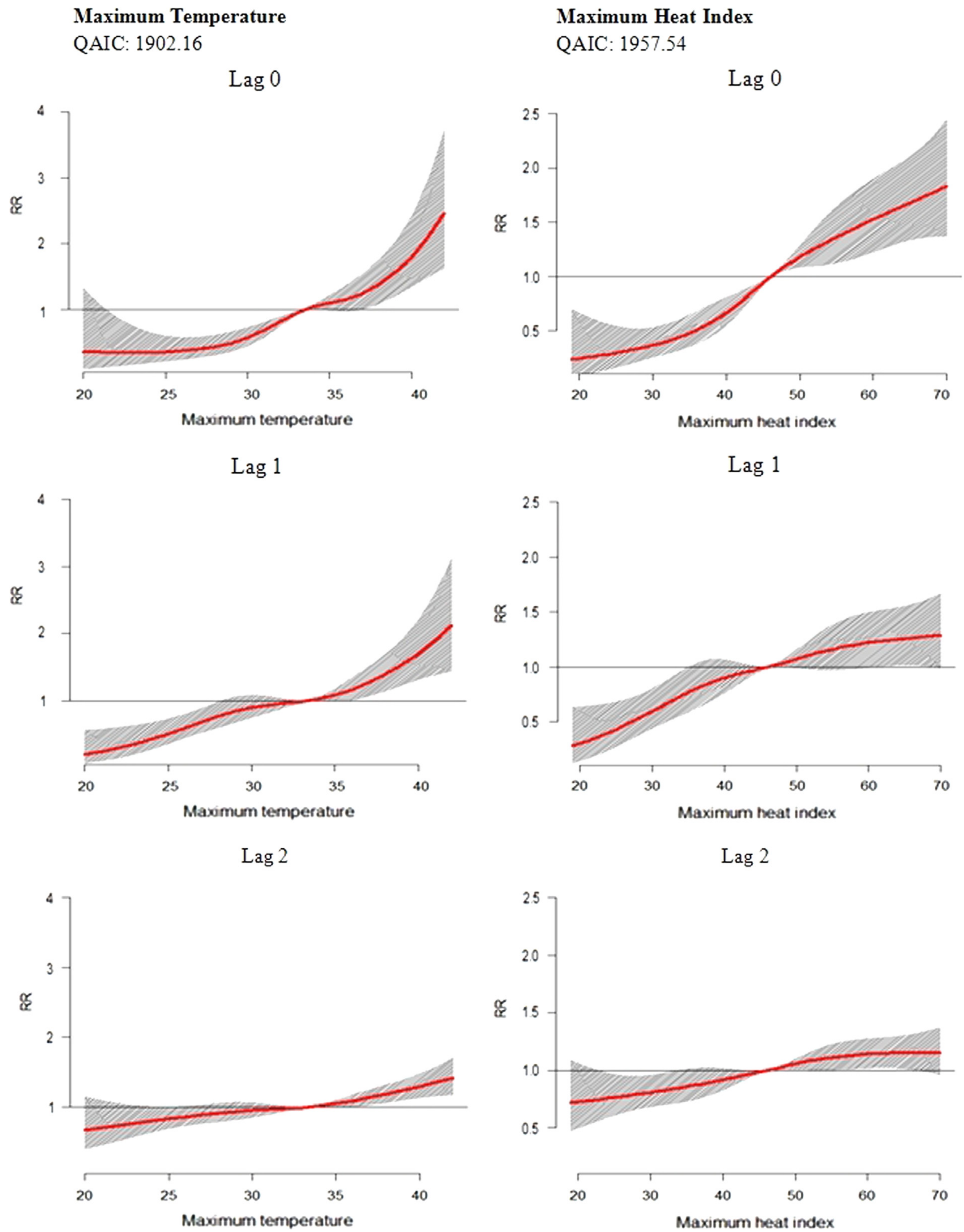

Fig. 2. Dose–response relationship using maximum temperature (left) and heat index (right) with the lagged effects. The reference values are median values of maximum temperature (33.5 °C) and heat index (46.1 °C) during June–August from 2011 to 2013.

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.

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

		Observed cases	Excess cases	
			Number	%
Year: 2011				
1st			*Compared with 2011*	
Period: 1–8 July	All	193	106.6	123.4
Duration (d): 8	0–15 y	18	12.0	200.0
Max temperature (°C)	16–44 y	92	50.0	119.0
Min: 35.2	45–64 y	63	32.8	108.6
Median: 36.9	65 y	20	11.9	146.9
Max: 38.8	Male	120	68.6	133.5
Median RH[a] (%): 68.5	Female	73	38.1	109.2
Median HI[b] (°C) : 59.0	Mild	184	101.7	123.6
	Severe	9	5.0	125.0
2nd				
Period: 20–26 July	All	111	12.6	12.8
Duration (d): 7	0–15y	4	−0.8	−16.7
Max temperature (°C)	16–44 y	63	12.5	24.8
Min: 35.0	45–64 y	33	2.3	7.5
Median: 35.5	65 y	11	0.8	7.8
Max: 36.7	Male	71	15.6	28.2
Median RH (%): 75.0	Female	40	−3.2	−7.4
Median HI (°C): 56.1	Mild	107	13.0	13.8
	Severe	4	−0.3	−7.0
Year: 2012				
1st			*Compared with 2012*	
Period: 30 June–14 July	All	650	244.4	60.3
Duration (d): 15	0–15y	57	24.9	77.6
Max temperature (°C)	16–44 y	318	118.1	59.8
Min: 35.2	45–64 y	207	78.3	60.8
Median: 37.1	65 y	68	24.7	57.4
Max: 39.0	Male	359	144.3	67.2
Median RH (%): 66	Female	291	100.0	52.6
Median HI (°C): 56.9	Mild	612	227.2	59.4
	Severe	38	17.0	81.0

[a] RH: relative humidity.
[b] HI: heat index.

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.

		Observed cases	Excess cases		Excess cases	
			Number	% *Compared with 2013*	Number	% *Compared with 2010–2012*
Year: 2013						
1st						
Period: 1–11 July	All	437	174.1	66.2	227.8	108.9
Duration (d): 11	Male	275	115.0	71.9	160.0	139.1
Max temperature (°C)	Female	162	59.4	57.9	67.8	72.0
Min: 35.5	0–15	18	7.5	71.4	2.3	14.6
Median: 37.1	16–44	210	82.2	64.3	107.1	104.1
Max: 37.7	45–64	159	64.8	68.8	90.8	133.1
Median RH[a] (%): 64	65	50	19.4	63.4	28.5	132.6
Median HI[b] (°C): 52.2	Mild	391	149.7	62.0	192.3	96.8
	Severe	46	24.1	110.0	35.5	338.1
2nd						
Period: 20 July–1 August	All	379	8.5	2.3	172.0	83.3
Duration (d): 13	Male	244	21.3	9.6	135.5	124.9
Max temperature (°C)	Female	135	−11.9	−8.1	37.5	38.5
Min: 36.1	0–15	18	1.5	10.3	6.3	53.8
Median: 39.6	16–44	187	0.4	0.2	82.2	78.4
Max: 41.2	45–64	125	4.4	3.6	59.4	90.5
Median RH (%): 59	65	49	1.4	2.9	26.3	115.9
Median HI (°C): 57.9	Mild	325	−7.6	−2.3	128.1	65.1
	Severe	54	16.0	42.1	45.2	513.6
3rd						
Period: 3–17 August	All	444	91.0	25.8	278.8	168.8
Duration (d): 15	Male	262	46.8	21.7	172.9	194.1
Max temperature (°C)	Female	182	42.5	30.5	106.3	140.4
Min: 35.9	0–15	15	1.7	11.3	6.4	74.4
Median: 39.1	16–44	226	49.0	27.7	141.2	168.4
Max: 42.1	45–64	135	24.2	21.8	81.8	153.8
Median RH (%): 60.0	65	68	16.1	31.0	48.9	256.0
Median HI (°C): 57.6	Mild	394	85.2	27.6	239.1	154.4
	Severe	50	5.6	12.6	39.9	395.5

[a] RH: relative humidity.
[b] HI: heat index.

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; Vaneckova 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 by the high degree of heat conduction, disrupted fluid balance, and no or delayed access to cooling. In the United States, the people who work outdoors have a 20-fold increased rate of heat-related death compared with persons in other forms of employment (CDC, 2008). We highlighted that comprehensive protective strategies should be built in workplaces exposing outdoor weather such as construction sites, road workers and farmers, as well as other emergency workers such as electricity workers.

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 stokes 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 symptoms and accurate measurement of core temperature is the first crucial step (Becker and Stewart, 2011). Immediate treatment including rapid cooling could greatly minimize the degree of cell damage that portends progression to organ failure (Becker and Stewart, 2011). Enhancing accuracy of emergent diagnosis and treatment is therefore vital for physicians, not only big hospitals but community medical institutions as well as paramedics to reduce mortality or morbidity due to serious heat diseases.

We used data from the National Heat-related Illness Surveillance System to examine local patterns of vulnerability in the current study. However, this analysis was restricted by limited patients' information which only includes age, sex, residence address and type of illnesses. According to previous literature, apart from age older than 65 or younger than 15 years, risk factors for heat-related illnesses varied: cognitive impairment and mental illness, heart and lung diseases, limited access to air-conditioning, alcohol intake, medications and substance use, obesity, physical disability, poor fitness level, strenuous outdoor activity during hottest daytime hours, urban residence living on the higher floors etc. (Becker and Stewart, 2011). Identification 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 5
Estimated effects of heat waves on heat-related illness in 2011–2013 with lagged effects.

	Lag 0		**Lag 0–2**		**Lag 0–5**	
	RR	95% CI	RR	95% CI	RR	95% CI
Year: 2011						
All	**1.505**	**1.101–2.059**	**2.032**	**1.520–2.716**	**2.370**	**1.686–3.332**
Male	**1.831**	**1.315–2.548**	**2.957**	**2.177–4.017**	**2.987**	**2.105–4.237**
Female	1.187	0.762–1.850	1.265	0.828–1.932	**1.776**	**1.069–2.950**
0–15	2.170	0.698–6.748	**3.250**	**1.053–10.032**	**4.956**	**1.439–17.066**
16–44	1.354	0.927–1.979	**2.675**	**1.859–3.850**	**2.883**	**1.903–4.368**
45–64	1.548	0.985–2.432	**1.686**	**1.098–2.588**	**1.825**	**1.100–3.026**
65–	**2.219**	**1.098–4.484**	1.218	0.603–2.461	1.901	0.833–4.335
Mild	**1.537**	**1.110–2.127**	**2.026**	**1.479–2.773**	**2.402**	**1.673–3.449**
Severe	1.564	0.591–4.136	**2.889**	**1.108–7.530**	2.528	0.743–8.595
Year: 2012						
All	**2.158**	**1.357–3.431**	**2.743**	**1.543–4.877**	**3.717**	**1.593–8.673**
Male	**2.253**	**1.237–4.104**	**2.488**	**1.174–5.274**	2.827	0.925–8.638
Female	**2.062**	**1.180–3.602**	**3.120**	**1.574–6.182**	**5.424**	**2.000–14.704**
0–15	4.186	0.823–21.298	2.475	0.367–16.683	1.698	0.103–27.816
16–44	**2.106**	**1.198–3.703**	**2.766**	**1.363–5.611**	**3.160**	**1.104–9.063**
45–64	**2.278**	**1.190–4.360**	**3.458**	**1.533–7.801**	**6.030**	**1.827–19.896**
65–	1.338	0.438–4.084	1.685	0.439–6.467	4.459	0.637–31.193
Mild	**2.093**	**1.307–3.350**	**3.138**	**1.752–5.621**	**4.349**	**1.847–10.236**
Severe	**6.978**	**1.765–27.579**	0.139	0.015–1.304	0.124	0.006–2.544
Year: 2013						
All	1.300	0.810–2.087	**1.802**	**1.079–3.011**	**1.791**	**1.028–3.118**
Male	**1.699**	**1.005–2.871**	**2.151**	**1.205–3.842**	**2.092**	**1.108–3.951**
Female	0.875	0.540–1.416	1.513	0.873–2.622	1.380	0.776–2.455
0–15	0.552	0.105–2.876	0.803	0.159–4.050	1.260	0.229–6.906
16–44	1.054	0.671–1.656	**1.684**	**1.041–2.724**	1.547	0.918–2.606
45–64	1.607	0.843–3.065	**2.017**	**1.021–3.983**	1.917	0.886–4.147
65–	1.996	0.917–4.344	**2.598**	**1.123–6.010**	**2.698**	**1.085–6.709**
Mild	1.144	0.716–1.828	**1.770**	**1.104–2.838**	1.564	0.915–2.673
Severe	**5.021**	**1.635–15.415**	**6.771**	**1.584–28.936**	**10.687**	**2.098–54.437**

RR: relative risk.
95% CI: 95% confidence interval. The bold means statistically significant ($p < 0.05$).

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 accessed 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 under-estimated. 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 during only three years with strong heat waves may lead to a 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.

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References

Anderson, G.B., Bell, M.L., 2011. Heat waves in the United States: mortality risk during heat waves and effect modification by heatwave characteristics in 43 U. S. communities. Environ. Health Perspect. 119, 210–218.

Becker, J.A., Stewart, L.K., 2011. Heat-related illness. Am. Fam. Physician 83, 1325–1330.

Centers for Disease Control and Prevention (CDC), 2006. Heat-related deaths – United States, 1999–2003. Morb. Mortal. Wkly. Rep. 55, 796–798.

Centers for Disease Control and Prevention (CDC), 2008. Heat-related deaths among crop workers – United States, 1992–2006. Morb. Mortal. Wkly. Rep. 57, 649–653.

Centers for Disease Control and Prevention (CDC), 2013. Heat illness and deaths – New York City, 2000–2011. Morb. Mortal. Wkly. Rep. 62, 617–621.

Chan, E.Y., Goggins, W.B., Yue, J.S., Lee, P., 2013. Hospital admissions as a function of temperature, other weather phenomena and pollution levels in an urban setting in China. Bull. World Health Organ. 91, 576–584.

Chen, R., Wang, C., Meng, X., Chen, H., Thach, T.Q., Wong, C.M., Kan, H., 2013. Both low and high temperature may increase the risk of stroke mortality. Neurology 81, 1064–1070.

Gasparrini, A., 2011. Distributed lag linear and non-linear models in R: the package dlnm. J. Stat. Softw. 43, 1–20.

Gasparrini, A., Armstrong, B., Kenward, M.G., 2010. Distributed lag non-linear models. Stat. Med. 29, 2224–2234.

Goggins, W.B., Chan, E.Y., Ng, E., Ren, C., Chen, L., 2012. Effect modification of the association between short-term meteorological factors and mortality by urban heat islands in Hong Kong. PLoS One 7, e38551.

Goldberg, M.S., Burnett, R.T., Stieb, D.M., Brophy, J.M., Daskalopoulou, S.S., Valois, M. F., et al., 2013. Associations between ambient air pollution and daily mortality among elderly persons in Montreal, Quebec. Sci. Total Environ. 463–464, 931–942.

Guo, Y., Barnett, A.G., Pan, X., Yu, W., Tong, S., 2011. The impact of temperature on mortality in Tianjin, China: a case-crossover design with a distributed lag nonlinear model. Environ. Health Perspect. 119, 1719–1725.

Guo, Y., Punnasiri, K., Tong, S., 2012. Effects of temperature on mortality in Chiang Mai city, Thailand: a time series study. Environ. Health 11, 36.

Hansen, A., Bi, P., Nitschke, M., Ryan, P., Pisaniello, D., 2008a. The effect of heat waves on mental health in a temperate Australian city. Environ. Health Perspect. 116, 1369–1375.

Hansen, A., Bi, P., Ryan, P., Nitschke, M., Pisaniello, D., Tucker, G., 2008b. The effect of heat waves on hospital admissions for renal disease in a temperate city of Australia. Int. J. Epidemiol. 37, 1359–1365.

IPCC, 2011. Summary for policymakers. In: Field, C.B., et al. (Eds.), Intergovernmental Panel on Climate Change Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. Cambridge University Press, New York, NY (Available from: 〈http://ipcc-wg2.gov/SREX/〉).

Kan, H.D., Jia, J., Chen, B.H., 2003. Temperature and daily mortality in Shanghai: a time-series study. Biomed. Environ. Sci. 16, 133–139.

Kim, Y.M., Park, J.W., Cheong, H.K., 2012. Estimated effect of climatic variables on the transmission of *Plasmodium vivax* malaria in the Republic of Korea. Environ. Health Perspect. 120, 1314–1319.

Lin, Y.K., Wang, Y.C., Lin, P.L., Li, M.H., Ho, T.J., 2013. Relationships between cold-temperature indices and all causes and cardiopulmonary morbidity and mortality in a subtropical island. Sci. Total Environ. 461–462, 627–635.

Lindstrom, S.J., Nagalingam, V., Newnham, H.H., 2013. Impact of the 2009 Melbourne heatwave on a major public hospital. Intern. Med. J. 43, 1246–1250.

Lowe, D., Ebi, K.L., Forsberg, B., 2011. Heatwave early warning systems and adaptation advice to reduce human health consequences of heatwaves. Int. J. Environ. Res. Public Health 8, 4623–4648.

Ma, W., Xu, X., Peng, L., et al., 2011. Impact of extreme temperature on hospital admission in Shanghai, China. Sci. Total Environ. 409, 3634–3637.

Na, W., Jang, J.Y., Lee, K.E., Kim, H., Jun, B., Kwon, J.W., Jo, S.N., 2013. The effects of temperature on heat-related illness according to the characteristics of patients during the summer of 2012 in the Republic of Korea. J. Prev. Med. Public Health 46, 19–27.

Rocklov, J., Forsberg, B., 2008. The effect of temperature on mortality in Stockholm 1998–2003: a study of lag structures and heatwave effects. Scand. J. Public Health 36, 516–523.

Rooney, C., McMichael, A.J., Kovats, R.S., Coleman, M.P., 1998. Excess mortality in England and Wales, and in Greater London, during the 1995 heatwave. J. Epidemiol. Community Health 52, 482–486.

Rothfusz, L.P., 1990. The Heat Index “Equation” or More Than You Ever Wanted to Know About Heat Index: National Weather Service Southern Region Technical Attachment SR/SSD 90-23. National Weather Service, Fort Worth, pp. 1–2.

Smith, J.E., 2005. Cooling methods used in the treatment of exertional heat illness. Br. J. Sports Med. 39, 503–507.

Stafoggia, M., Forastiere, F., Agostini, D., Biggeri, A., Bisanti, L., Cadum, E., et al., 2006. Vulnerability to heat-related mortality: a multicity, population-based, case-crossover analysis. Epidemiology 17, 315–323.

Tian, Z., Li, S., Zhang, J., Jaakkola, J.J., Guo, Y., 2012. Ambient temperature and coronary heart disease mortality in Beijing, China: a time series study. Environ. Health 11, 56.

Toloo, G., FitzGerald, G., Aitken, P., Verrall, K., Tong, S., 2013. Evaluating the effectiveness of heat warning systems: systematic review of epidemiological evidence. Int. J. Public Health 58, 667–681.

Vaneckova, P., Beggs, P.J., de Dear, R.J., McCracken, K.W., 2008. Effect of temperature on mortality during the six warmer months in Sydney, Australia, between 1993 and 2004. Environ. Res. 108, 361–369.

Williams, S., Nitschke, M., Parton, K.A., Weinstein, P., Bi, P., 2012. The impact of summer temperatures and heatwaves on mortality and morbidity in Perth, Australia 1994–2008. Environ. Int. 40, 33–38.

Wichmann, J., Andersen, Z., Ketzel, M., Ellermann, T., Loft, S., 2011. Apparent temperature and cause-specific emergency hospital admissions in Greater Copenhagen, Denmark. PLoS One 6, e22904.

Wu, W., Xiao, Y., Li, G., Zeng, W., Lin, H., Rutherford, S., Xu, Y., Luo, Y., Xu, X., Chu, C., Ma, W., 2013. Temperature-mortality relationship in four subtropical Chinese cities: a time-series study using a distributed lag non-linear model. Sci. Totoal. Environ. 449, 355–362.

Xie, H., Yao, Z., Zhang, Y., Xu, Y., Xu, X., Liu, T., Lin, H., Lao, X., Rutherford, S., Chu, C., Huang, C., Baum, S., Ma, W., 2013. Short-term effects of the 2008 cold spell on mortality in three subtropical cities in Guangdong Province, China. Environ. Health Perspect. 121, 210–216.

Yang, J., Liu, H.Z., Ou, C.Q., Lin, G.Z., Ding, Y., Zhou, Q., Shen, J.C., Chen, P.Y., 2013. Impact of heat wave in 2005 on mortality in Guangzhou, China. Biomed. Environ. Sci. 26, 647–654.

Yu, W., Vaneckova, P., Mengersen, K., Pan, X., Tong, S., 2010. Is the association between temperature and mortality modified by age, gender and socio-economic status? Sci. Total Environ. 408, 3513–3518.

Zanobetti, A., O'Neill, M.S., Gronlund, C.J., Schwartz, J.D., 2013. Susceptibility to mortality in weather extremes: effect modification by personal and small-area characteristics. Epidemiology 24, 809.

Zhang, Y., Nitschke, M., Bi, P., 2013. Risk factors for direct heat-related hospitalization during the 2009 Adelaide heatwave: a case crossover study. Sci. Total Environ. 442, 1–5.