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The impact of heat waves and cold spells on respiratory emergency department visits in Beijing, China

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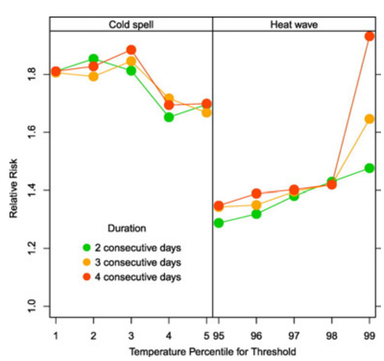
HIGHLIGHTS

- The minimum respiratory emergency department admissions temperature was 21.5 °C.
- The health effects of heat waves and cold spells showed different change trends.
- The added effects of extreme temperatures were small and negligible.

GRAPHICAL ABSTRACT



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ABSTRACT

The objectives of this article were (i) to find the association between extreme temperatures and respiratory emergency department (ED) visits and (ii) to explore the added effects of heat waves and cold spells on respiratory ED visits in Beijing from 2009 to 2012. A quasi-Poisson generalised linear model combined with a distributed lag non-linear model was performed to quantify this association. The results indicated that (i) ambient temperature related to respiratory ED visits exhibited a U-shaped association. The minimum-morbidity temperature was 21.5 °C. (ii) the peak relative risk (RR) of cold spells on respiratory ED visits was observed in relatively mild cold spells with a threshold below the 3rd percentile for 4 days (RR = 1.885, 95% CI: 1.300–2.734), and there was a reduction in risk during extremely chilly cold spells (RR = 1.811, 95% CI: 1.229–2.667). However, the risk of heat waves increased with the thresholds, and the greatest risk was found for extremely hot heat waves (RR = 1.932, 95% CI: 1.461–2.554). (iii) the added effect of heat waves was small, and we observed that the added heat wave effect only introduced additional risk in females (RR = 1.166, 95% CI: 1.007–1.349). No added effect of cold spells was identified. In conclusion, the main effects of heat waves and cold spells on respiratory ED visits showed different change trends. In addition, the added effects of extreme temperatures on respiratory ED visits were small and negligible.

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1. Background

Projections of the Intergovernmental Panel on Climate Change (IPCC) show that extreme weather events are likely to become more frequent and intense in the coming decades (Stocker et al., 2013). Prolonged periods of excessively hot or cold weather can be described as heat waves or cold spells. The frequency of heat waves has increased in large parts of Asia, Europe and Australia (Pachauri et al., 2014). Furthermore, heat-related human mortality has increased with global warming (Pachauri et al., 2014). Although cold spells will decrease over most land areas as the global mean temperature increases, the effects of cold spells generally persist longer than the effects of heat waves. Therefore, cold spells are still a major environmental threat to human health (Analitis et al., 2008; Montero et al., 2010; Pachauri et al., 2014; Ryti et al., 2016). The health effects of extreme temperatures have two contributions: main and added effects. An increased risk due to the independent effects of daily temperature levels is the main effect, while an additional risk due to the duration of extreme temperatures sustained for several consecutive days is the added effect (Gasparrini and Armstrong, 2011). A series of studies has assessed the added effects of extreme temperatures in some regions (Gasparrini and Armstrong, 2011; Huang et al., 2012; Phung et al., 2016). However, no study has comprehensively investigated the main and added effects of heat waves and cold spells on respiratory morbidity in China.

Beijing is the most populous city and the third largest Chinese city by urban population. The east longitude of Beijing is 115°25′–117°30′ and the north latitude is 39°28′–41°05′. In Beijing, the altitude of the plains is 20–60 m, while the altitude of the mountains is 1000–1500 m. Beijing has a monsoon-influenced semi-humid continental climate, and there has been evident climate warming in recent decades. The linear warming rate of the annual mean temperature in Beijing was 0.39 °C/10a during the period from 1960 to 2008, which was higher than the global warming rate (0.13 °C/10a) (Solomon et al., 2007; Zuofang et al., 2011). It is meaningful and necessary to evaluate the impact of extreme temperatures on respiratory disease in Beijing.

Respiratory disease is a common and significant disease around the world, and it has a high prevalence and heavy burden of disease (Chang and Rivera, 2013). Respiratory disease-related death ranked third in non-communicable diseases, which is just behind cardiovascular diseases and cancers (GBD, 2016). Approximately 3.9 million people die every year for respiratory disease (GBD, 2016). Climate change is a major threat to respiratory health. It could directly promote or aggravate respiratory disease or indirectly increase exposure to risk factors for respiratory disease (Ayres et al., 2009). Additionally, extreme temperatures are the key climatic change factors that could potentially cause respiratory disease (Ayres et al., 2009). The objectives of this article were (i) to find the association between extreme temperatures and respiratory emergency department (ED) visits and (ii) to explore the added effects of heat waves and cold spells on respiratory ED visits.

2. Methods

2.1. Data source

Daily emergency room visits of three comprehensive hospitals in the Haidian district of Beijing were collected from 1 January 2009 to 31 November 2012. The data included the date and cause of ED visits, age, sex, primary diagnosis and address. Respiratory disease (ICD-10: J00-J99), upper respiratory disease (J00-J06, J30-J39), and lower respiratory disease (J20-J22, J40-J47) were classified according to the 10th revision of International Classification of Diseases. Further, visits from people living outside Beijing were excluded. To analyse the difference in effectiveness according to personal characteristics, we divided respiratory ED visits by gender (male and female) and age (65 years as a cut-off point).

Meteorology data, including daily mean temperature, daily minimum temperature, daily maximum temperature, and relative humidity, were obtained from the China Meteorological Data Sharing Service System (http://data.cma.cn/). Daily mean temperature was used in our study because studies have indicated that mean temperature is a representative temperature exposure index in evaluating the health effects of ambient temperature (Gasparrini et al., 2015; Guo et al., 2014; Hajat et al., 2006). Air pollution data for 24-h average thoracic particles (PM_{10}), nitrogen dioxide (NO_2) and sulfur dioxide (SO_2) were extracted from the China National Environmental Monitoring Centre (http://www.cnemc.cn/).

2.2. Definitions of heat waves and cold spells

Various definitions of heat waves and cold spells were used in different studies, and the reasons for these differences may include author preferences and locational differences (Anderson and Bell, 2011; Bobb et al., 2014; Hertel et al., 2009; Song et al., 2017). In this study, we defined heat waves and cold spells by a combination of temperature intensity and duration. (i) Thresholds: mean temperature exceeding the 95th, 96th, 97th, 98th, and 99th percentiles of the year-round distribution for heat waves, with a mean temperature under the 1st, 2nd, 3rd, 4th and 5th percentiles for cold spells; (ii) Duration: at least 2 to 4 consecutive days with mean temperature above or below the thresholds.

2.3. Statistical analysis

Statistical analysis in this study consisted of two steps. First, the main effects of heat waves and cold spells were examined. Second, the added effects of heat waves and cold spells were estimated. A generalised linear model (GLM) with quasi-Poisson family and a distributed lag non-linear model (DLNM) were applied to evaluate the impact of extreme temperatures on respiratory ED visits. We adjusted for long-term trends and seasonality. In addition, relative humidity, PM_{10}, NO_2, SO_2 and day of week were also adjusted. Q-AIC, a modification of the Akaike Information Criterion (AIC), was used to estimate the relative goodness of quasi-likelihood model fit (Peng et al., 2006). The model is described in the following equation.

$$\begin{aligned}\log(\mu_t) = \alpha + \beta_m T_{tm,l} + \beta_a T_{ta,l} + \mathrm{ns}(\mathrm{Time}, 4^{*}\mathrm{year}) + \mathrm{ns}(\mathrm{RH}_t, 4) \\ + \mathrm{ns}\ (\mathrm{PM}_{10t}, 4) + \mathrm{ns}\ (\mathrm{SO}_{2t}, 4) + \mathrm{ns}\ (\mathrm{NO}_{2t}, 4) + \gamma \mathrm{DOW}_t \\ + \delta \mathrm{Holiday}_t\end{aligned} \quad (1)$$

where t is the observation day, $Y_t$is the daily count of respiratory ED visits on day t, $Y_t$was presumed to follow an overdispersed Poisson distribution for each day, α is the intercept, and $T_{tm,l}$ and $T_{ta,l}$ are the matrixes obtained by applying the DLNM model to temperature for main and added effects. ns(Time,df) is a natural cubic spline of time, which was used to control long-term trend and seasonality. The degree of freedom (df) of time was 4 per year; RH is the relative humidity; DOW is the day of week, which is a categorical variable, and Sunday was chosen as a reference; Holiday is a binary variable, which is “1” for a public holiday; and β, γ, and δ are coefficients.

In the first step, the main effect on day t is modelled by a natural cubic spline with 4 degrees of freedom (df) in the temperature space and a natural cubic spline with 5 df in the lag space. The effects of cold have a longer lag up to two to three weeks (Ye et al., 2012). Thus, we set the maximum lag of the main and added effects as 21 days, which was consistent with previous studies (Barnett et al., 2012; Gasparrini et al., 2015; Guo et al., 2014; Phung et al., 2016). The relative risk (RR) of main effect was calculated by comparing the median temperature among heat waves (cold spells) with the reference temperature. In the second step, we investigated the potential added effects of extreme temperatures. The indicator $T_{ta,l}$ was coded as a dichotomous variable, which assumes a value of 1 if the mean temperature is above or below the threshold for at least 2 to 4 consecutive days. The added effect is examined as the exponential of the coefficient for the indicator.

The temperature with the lowest morbidity was chosen as the reference temperature. To identify the threshold value, we visualised the possible range of the threshold using a temperature and ED visits plot with a natural cubic spline in the temperature space. Then, we used a threshold model for analysis and used 0.1°C increases in mean temperature within the possible range (Gasparrini, 2014). The temperature corresponding to the model with the lowest Q-AIC was chosen as the threshold temperature. All analyses were performed using R 3.3.2 software (http://www.r-project.org). The "mgcv" and "dlnm" packages of R were used. Statistical significance was considered as a two-sided $p < 0.05$.

3. Results

Table 1 shows a summary of the daily respiratory ED visits, ambient temperature, relative humidity, and air pollutants. The total number of respiratory ED visits in the study was 257,140, and the number of daily respiratory ED visits varied from 50 to 647. There were 11.5 respiratory ED visits of the elderly per day. The mean temperature was as high as 34.5 °C, with an average mean temperature of 15.5 °C over the study period in Beijing.

3.1. Association between temperature and respiratory ED visits

Fig. 1 illustrates that the pooled association between temperature and respiratory ED visits exhibited a U-shaped relationship. The minimum-morbidity temperature was 21.5 °C. Table 2 summarises statistics for the number of cold spells and heat waves. There were 5 days for extremely chilly cold spell (temperature below 1st percentile with 4 days). However, there was only 1 day for extremely hot heat wave (temperature above 99th percentile with 4 days).

3.2. The main effects of heat waves and cold spells

The relative risks of heat waves increased with the increase in the thresholds from the 95th to the 99th percentile, and the greatest risk was observed for the extremely hot heat wave at the 99th percentile for 4 days (RR = 1.932, 95% CI: 1.461–2.554). However, when the cold spell thresholds decreased from the 5th to the 1st percentile, the RR first increased and then decreased (Fig. 2). The greatest risk was not identified in the extremely chilly cold spell (RR = 1.811, 95% CI: 1.229–2.667), though it was observed in a relatively mild cold spell, in which the threshold was below the 3rd percentile for 4 days (RR = 1.885, 95% CI: 1.300–2.734). On the other hand, there was an increased risk of respiratory ED visits during cold spells (Fig. 2).

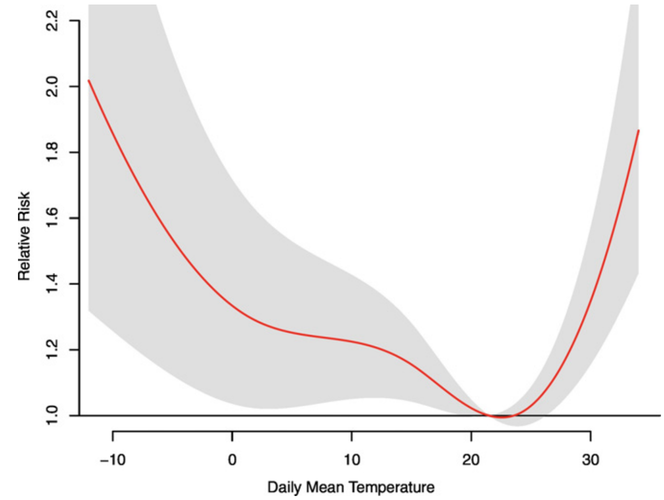

Fig. 1. The pooled association between ambient temperature and respiratory emergency department visits (PDF format, 2-column fitting image).

Compared with males, females have increased vulnerability to the effects of heat waves and cold spells (Fig. S1). The analysis of age showed that no effects of heat waves were observed in the elderly, except for heat waves that were defined by a threshold above the 99th percentile for 3 or 4 days. However, risks of cold spells defined by all thresholds for 3 or 4 days in the elderly were significantly higher than in the younger group, except for cold spells that were defined by a threshold below the 4th percentile for 3 days (Fig. S2). In addition, the analysis of cause-specific respiratory morbidity demonstrated that increased risks of upper respiratory morbidity were observed during heat waves, whereas no effects of upper respiratory morbidity were found during cold spells. However, there were statistically significant increases in lower respiratory morbidity during cold spells, but no effects of lower respiratory morbidity were observed during heat waves (Table S1).

3.3. The added effects of heat waves and cold spells

There was no significance for the added effects of heat waves and cold spells on respiratory ED visits matching our definitions in all populations. We only observed a small added effect of heat waves in females with a temperature above the 96th percentile for 4 days' duration (RR = 1.166, 95% CI: 1.007–1.349). Additionally, no added effect of cold spells was observed in females and the elderly. Partial data of added effect were presented in Fig. 3.

Table 1
Summary statistics for daily respiratory emergency department visits, climate variables, and air pollutants in Beijing from 2009 to 2012.

Variables	Mean (SD)	Minimum	25th	50th	75th	Maximum
Total respiratory morbidity	176.0(64.0)	50	135	165	203	647
Upper respiratory morbidity	115.3(39.4)	32	89	109	132	445
Lower respiratory morbidity	14.5(8.0)	1	9	13	18	62
Age						
0–64 years	164.5(61.2)	47	126	153	189	635
65-years	11.5(5.6)	0	8	11	15	44
Gender						
Male	98(35.2)	33	75	91	113	375
Female	78(30.5)	14	59	73	91	272
Climate variables						
Mean temperature (°C)	13.1 (11.6)	−12.5	1.7	15.1	24	34.5
Relative humidity (%)	50.5 (20.1)	9.0	34.0	52.0	67.0	97.0
Environment variables						
PM_{10} (mg/m^3)	116.0 (76.4)	6.3	63.9	101.9	147.0	801.6
SO_2 (mg/m^3)	30.7 (30.0)	4.9	10.0	19.1	40.1	201.6
NO_2 (mg/m^3)	54.5 (23.4)	9.0	38.9	50.1	64.3	167.4

Abbreviations: SD: Standard Deviation.

Table 2
Respiratory emergency department visits due to main effects of cold spells and heat waves in Beijing.

No. of consecutive days	Cold spells			Heat waves		
	Percentile	Days	RR (95%CI)	Percentile	Days	RR (95%CI)
≥2	≤5th	45	1.696 (1.192, 2.415)	≥95th	47	1.288 (1.104, 1.503)
	≤4th	36	1.652 (1.156, 2.361)	≥96th	36	1.319 (1.127, 1.544)
	≤3th	27	1.813 (1.265, 2.599)	≥97th	26	1.381 (1.159, 1.646)
	≤2th	17	1.854 (1.268, 2.711)	≥98th	15	1.429 (1.191, 1.714)
	≤1th	10	1.811 (1.226, 2.676)	≥99th	9	1.476 (1.222, 1.782)
≥3	≤5th	28	1.668 (1.172, 2.374)	≥95th	29	1.343 (1.139, 1.584)
	≤4th	23	1.717 (1.199, 2.459)	≥96th	22	1.350 (1.143, 1.594)
	≤3th	18	1.846 (1.282, 2.660)	≥97th	17	1.396 (1.169, 1.667)
	≤2th	11	1.793 (1.228, 2.617)	≥98th	10	1.419 (1.185, 1.700)
	≤1th	7	1.806 (1.225, 2.662)	≥99th	4	1.646 (1.313, 2.063)
≥4	≤5th	20	1.699 (1.186, 2.433)	≥95th	21	1.348 (1.144, 1.588)
	≤4th	18	1.694 (1.181, 2.431)	≥96th	14	1.389 (1.167, 1.654)
	≤3th	13	1.885 (1.300, 2.734)	≥97th	12	1.402 (1.175, 1.672)
	≤2th	7	1.828 (1.253, 2.667)	≥98th	7	1.419 (1.187, 1.695)
	≤1th	5	1.811 (1.229, 2.667)	≥99th	1	1.932 (1.461, 2.554)

Abbreviations: RR: Relative Risk.

4. Discussion

To our knowledge, this is the first study to comprehensively investigate the main and added effects of heat waves and cold spells on respiratory morbidity in China. Ambient temperature was related to respiratory ED visits, exhibiting a U-shaped association. The minimum-morbidity temperature was 21.5 °C. The peak risk of cold spells in respiratory ED visits was observed in relatively mild cold spells, and the risk was decreased during extremely chilly cold spells. However, the risk of heat waves increased with thresholds, and the greatest risk was observed in extremely hot heat waves. The added effect of heat waves was small and was apparent only in females. No added effect of cold spells was observed.

4.1. Main effects of extreme temperatures on respiratory ED visits showed different change trends

The peak risk of cold spells on respiratory ED visits was observed in relatively mild cold spells, and there was a reduced risk during extremely chilly cold spells. However, the main effects of heat waves and cold spells on respiratory ED visits showed different change trends. The relative risk of heat waves increased with thresholds, and the greatest risk was observed in extremely hot heat waves. Our results were consistent with a study conducted in the United States (Barnett et al., 2012). There are several possible causes for the results. First, the public is better able to cope with extreme cold than with extreme heat. People implement adequate preventive measures before extreme cold weather occurs, such as wearing warm clothing and staying indoors. Second, the public may have a worse ability to adopt appropriate measures in extreme heat waves. When wearing light clothes and drinking cold water could not make people feel cool, staying in air-conditioned rooms is most people's choice. However, the number of people who have air conditioning in their homes is still not high. Furthermore, some people may feel uncomfortable when staying in air-conditioned places for an extended period of time, and may even believe that air conditioning is unhealthy.

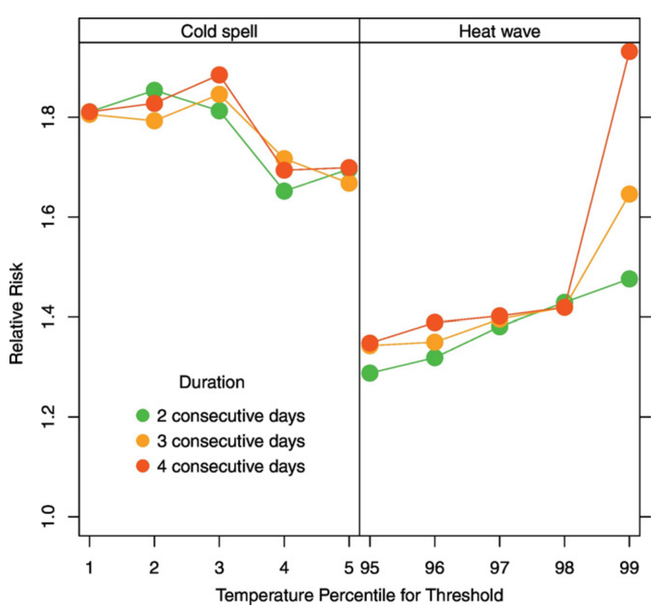

Fig. 2. Relative risk in daily respiratory morbidity due to the main effects of cold spells and heat waves according to the threshold and duration (PDF format, 2-column fitting image).

On the other hand, there was an increased risk of respiratory ED visits in Beijing during cold spells. A systematic evaluation in 306 communities from 12 countries/regions conducted by Yuming Guo showed that effect estimates for cold effects were higher than those for heat effects in all countries or regions (Guo et al., 2014). In addition, a multicountry observational study performed by Gasparrini and his team indicated that most of the temperature-induced mortality burden was attributable to cold temperatures (Gasparrini et al., 2015). Therefore, reducing the respiratory harm induced by cold temperatures should be a significant concern of governments.

4.2. Added effects of extreme temperatures on respiratory ED visits were small and negligible

Compared with the main effects of extreme temperatures, the added effects were small and negligible. In our study, we observed that the added heat wave effect only introduced additional risk in females at a temperature above the 96th percentile with 4 days' duration. The results were consistent with previous research that analysed the added effect of heat waves on mortality in the United States (Gasparrini and Armstrong, 2011). The investigation found that the added effect of heat waves was apparent only after 4 consecutive days (RR = 1.028, 95%CI: 1.004–1.053). Our results suggested that the independent effect of increased daily temperature was larger than the duration of heat sustained for several consecutive days. The independent effect of high daily temperature was the main risk factor for the general population, which could make people uncomfortable. Sustained heat would mildly increase discomfort for vulnerable populations. Furthermore, no added effect of cold spells was observed in our study, which suggested that excess risk during cold spells was attributed to the drop in daily temperatures.

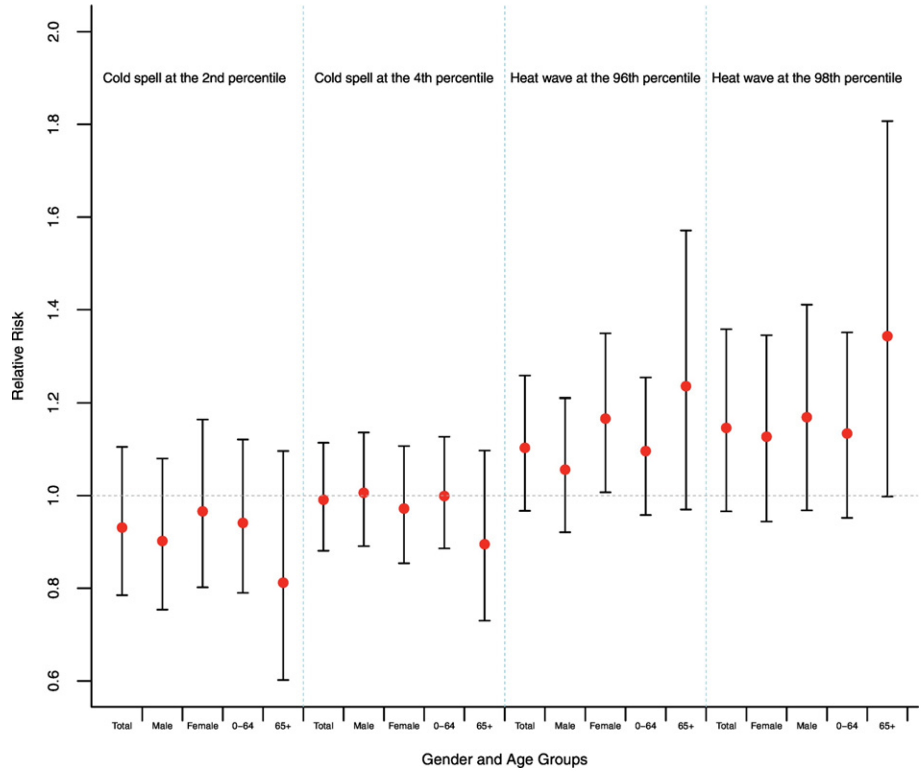

Fig. 3. Relative risk of daily respiratory morbidity associated with the added effects of cold spells and heat waves in different subgroups (PDF format, 2-column fitting image).

4.3. Cause-specific respiratory disease and populations vulnerable to extreme temperatures

Our study illustrated that females were more vulnerable to heat waves and cold spells. In addition, we observed that the elderly did not frequently have respiratory diseases during heat waves, except for extremely hot heat waves. However, the elderly had increased vulnerability to cold spells with long duration (3–4 days). The results are consistent with previous research evaluating the effects of cold spells on mortality (Zhou et al., 2014). However, limited studies have analysed the effects of heat waves and cold spells on morbidity according to gender and age, which should be further investigated in the future (Huang et al., 2012).

On the other hand, results indicated that populations were more susceptible to upper respiratory disease during heat waves and vulnerable to lower respiratory disease during cold spells. The substantial connection between upper and lower airway disease could explain the results. First, upper respiratory disease could be regarded as a risk factor for lower respiratory disease. Second, upper respiratory disease is a marker of a population vulnerable to lower respiratory disease or other airway disease. Third, upper respiratory disease has even been regarded as a stage of lung impairment (Corren et al., 2003).

4.4. Mechanisms of the effect of temperature on respiratory disease

Inhalation of cold air causes cooling of the nasal airway and bronchial mucosa, which impairs ciliary motility and increases suffering from respiratory disease (Clary-Meinesz et al., 1992; Eccles, 2002). The biological mechanism behind the association may be related to influenza activity and excited vagal afferent fibres. A study analysing data from 85 countries showed that peak influenza activity occurred during the coldest month or the month after the coldest month (Azziz Baumgartner et al., 2012). Furthermore, more frequent influenza activity was found in temperature regions (37%) compared with subtropical (17%) and tropical regions (6%). Vagal afferent fibres are thought to be associated with cold-related respiratory responses through the autonomic nerve reflex (Xing et al., 2008). Autonomic respiratory responses include cough, airway constriction and mucosal secretion. A study has shown that vagal afferent fibres express TRPM8 receptors in some populations, and that the activation of TRPM8 by cold leads to autonomic nerve reflex (Xing et al., 2008). In addition, hot temperatures were also related to respiratory disease. Patients with pre-existing chronic pulmonary disease seemed to be more vulnerable to heat-induced diseases during heat waves (Kenny et al., 2010). The cause is physiological impairments in the regulation of core body temperature in a hot environment (Kenny et al., 2010). Moreover, they have a poor ability to dissipate excess heat, which increases their risk of suffering from heat stress conditions, such as dehydration and heatstroke (De Sario et al., 2013).

4.5. Suggestions for adaptation to extreme temperatures

Our study demonstrated that the relative risk of heat waves increased with thresholds, and the greatest risk was observed in extremely hot heat waves. Therefore, governments should improve health responses to heat waves, especially for extremely hot heat waves. A series of studies has shown a higher prevalence of air conditions associated with a lower health risk, and the association was more significant for central air (Chen et al., 2016; O'Neill et al., 2005). Therefore, governments should improve installation and public services. On the other hand, researchers have proved that the number of expected deaths was reduced after heat-wave system implementation (Ebi et al., 2004; Fouillet et al., 2008; Weisskopf et al., 2002). Therefore, sophisticated heat-wave systems should be studied. A good example is the Canadian hot weather health-response plan. Heat waves have affected most areas of Canada to varying degrees, and most heat stress events occur in Ontario and Quebec (Smoyer-Tomic et al., 2003). Toronto's heat-wave system has been proved to be effective in beating the heat, which is an essential early step for adaptation to hot weather

(Smoyer-Tomic and Rainham, 2001). Their experience is worthy of further examination. The government asks the centre for disease control and hospitals to declare a heat warning and to make full use of non-profit organisations. The media disseminates the effective preventive measures to the public. Females, the elderly and homeless people should be particularly protected.

The peak risk of cold spells on respiratory morbidity was observed in relatively mild cold spells, and there was a reduced risk during extremely chilly cold spells. Consequently, finding effective and easily available measures against cold is essential. Therefore, meteorological departments should strive for a timely forecast of cold spells. In addition, governments should require that related departments adequately prepare for cold spells as its start, which could greatly decrease morbidity induced by cold spells. Warming the house is one of the essential components in the fight against extreme cold spells. A study conducted in London suggested that several thousand people in the United Kingdom every year could be saved by improvements to their homes (Wilkinson et al., 2001). Furthermore, Donaldson and his team suggested that a combination of warm clothing and warming houses could decrease cold-related mortality despite a high level of outdoor excursions (Donaldson et al., 1998). Therefore, governments should improve cold-warning systems and take effective measures; meanwhile, the public should raise self-protection awareness. People, especially vulnerable populations, should spend more time in warm rooms and put on layers of clothing during cold spells.

4.6. Strengths and limitations

Several strengths to our study should be noted. First, to our knowledge, this is the first study to comprehensively investigate the main and added effects of heat waves and cold spells on respiratory ED visits in China. The results indicated that the main effects of heat waves and cold spells on respiratory ED visits showed different change trends. Second, the "dlnm" model in R was used in our study. The "dlnm" model could estimate the non-linear and delayed relationship between ambient temperature and morbidity using a two-dimensional spline function (Armstrong, 2006; Gasparrini et al., 2010). We combined DLNM with GLM, which is more flexible than a single expose-response model. In addition, a threshold model was performed to accurately identify the threshold value. Potential limitations should also be considered. First, data from only one city were analysed in our study. Thus, the conclusions may not be generalizable to other regions. Second, meteorology and air pollution data from monitoring stations might not represent personal exposure. Data on individual exposure are not available. Thus, bias may exist in the results.

5. Conclusions

Ambient temperature is related to respiratory ED visits with a U-shaped association. The minimum morbidity temperature was 21.5 °C. The peak risk in cold spells on respiratory ED visits was observed in relatively mild cold spells, and there was a reduction in risk during extremely chilly cold spells. However, the relative risks of heat waves increased with thresholds, and the greatest risk was observed in extremely hot heat waves. The added effects of extreme temperatures were small and negligible. In our study, we observed that the added heat wave effect only introduced additional risk in females, and no added effect of cold spells was found. In addition, upper respiratory disease has increased risks during heat waves, whereas lower respiratory disease has increased risks during cold spells.

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.scitotenv.2017.09.108.

Conflict of interest

We declare that all authors have no competing interests.

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