Letter

Life loss per death of respiratory disease attributable to non-optimal temperature: results from a national study in 364 Chinese locations

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Abstract

Many studies have linked temperature with respiratory deaths, but epidemiological evidence of temperature-attributable years of life lost (YLL) from respiratory diseases is limited. Daily respiratory YLL rates were calculated using mortality data from 364 locations of China during 2006–2017, and meteorological data were collected for the same period. First, the distributed lag non-linear model (DLNM) was applied to estimate specific temperature-respiratory YLL rate associations in each location. Then multivariable meta-analysis was conducted to pool the location-specific estimates. Finally, we calculated the average life loss per death (LLD) to quantify the respiratory mortality burden of non-optimal temperature. Subgroup analyses were conducted by gender, age, region and cause of death. Inversely J-shaped association was observed between non-optimal temperature and respiratory YLL rate in China. The minimum YLL-rate temperature was 26.9°C nationwide. An average of 1.37 years (95% CI: 1.06–1.65) LLD was attributable to non-optimal temperatures with 2.06 years (95% CI: 1.57–2.60) for pneumonia, 2.03 years (95% CI: 1.76–2.31) for chronic lower respiratory infections (LRTI), 0.88 years (95% CI: 0.65–1.09) for chronic obstructive pulmonary disease (COPD), most of which was attributed to moderate cold (0.73 years, 95% CI: 0.65–0.80). LLD caused by non-optimal temperature was higher in males, the young, and north China. Exposure to non-optimal temperature increases respiratory YLL rate in China, most of which were attributed to moderate cold. People with respiratory diseases including pneumonia, chronic LRTI and COPD are vulnerable to non-optimal temperature exposure. The result of this study provides useful information to reduce temperature-related respiratory disease burden.
1. Introduction

Respiratory diseases are among the major causes of morbidity and mortality worldwide. According to the Global Burden of Disease (GBD) Study, the chronic respiratory diseases caused 3.91 million deaths and 68 million years of life lost (YLL) in 2017 (Roth et al. 2018). Among which, lower respiratory tract infections (LRTI) and chronic obstructive pulmonary disease (COPD) ranked among the five leading causes of disability adjusted life years (DALYs) globally (2018b), while pneumonia is the world’s leading cause of death among children under five years of age, killing approximately 0.88 million children in 2017 (GBD 2019).

Non-optimal temperature-mortality relationship and its heterogeneity across cities or countries have been well documented (Guo et al. 2013, Gasparrini et al. 2015, Ban et al. 2017, Silveira et al. 2019). Numerous epidemiological studies have demonstrated the associations between non-optimal temperature and respiratory mortality (Gasparrini et al. 2015, Chen et al. 2018). Most of those studies focused on the death counts (Gasparrini et al. 2015, Luo et al. 2019, Ma et al. 2019), which could not indicate the extent to which lives are shortened by exposure to non-optimal temperature from a public health perspective (Rocklov et al. 2009, Odhiambo Sewe et al. 2018).

As a part of DALYs, YLL can be used to estimate mortality burden. Increasing evidence suggested that YLL could be an important metric in environmental health (Huang et al. 2012, Guo et al. 2013, Odhiambo Sewe et al. 2018). Compared with mortality, YLL takes both the number of deaths and age at death into consideration by assigning greater weights to deaths at younger ages (Zhang et al. 2018). However, limited studies have estimated the association between non-optimal temperature and respiratory YLL. Therefore, it is unclear to what extent does non-optimal temperature exposure reduce life years. To fill the knowledge gap, we introduced average life loss per death (LLD) of respiratory mortality caused by non-optimal temperature, which represents the years respiratory death may prematurely lose if he/she exposes to non-optimal temperature. To help the public and policy-makers understand the magnitude of adverse health effects caused by non-optimal temperature intuitively.

China suffers from heavy disease burden of respiratory diseases (Zhou et al. 2019), at the same time it is also significantly affected by global warming (Change 2019). In the context of climate change, it is imperative to conduct a nationwide study to comprehensively assess the effect of non-optimal temperature on respiratory YLL, which could provide information for estimating the future impacts of climate change in China.

In this study, we conducted a nationwide study including 364 locations in China. We aimed to examine the association of non-optimal temperature with respiratory YLL rate, and quantify the average LLD attributable to non-optimal temperature.

2. Materials and methods

2.1. Study settings

Study locations in Yunnan, Guangdong, Hunan, Zhejiang, and Jilin provinces were selected based on provincial mortality surveillance systems. Locations in other provinces were selected based on the China’s Disease Surveillance Points System (DSPS) (Ma et al. 2015, Liu et al. 2016) (section 1.1 in appendix (available online at stacks.iop.org/ERL/16/035001/mmedia)). Study locations from both provincial surveillance system and DSPS were chosen if they met at least one of the two criteria: (a) population sizes over 200,000, (b) annual mortality rates >4% (Ma et al. 2015). Finally, 364 locations were selected and categorized into north China (68 locations) and south China (296 locations) according to China’s Qinling Mountains and Huaihe River range (latitude ≈ 34°) (see figure S1) (Hu et al. 2017). Not only natural geography but also culture and heating policy differ substantially on the northern and southern sides of Qinling Mountains and Huaihe River range (Ebenstein et al. 2017).

This study was approved by the Ethics Committee of Guangdong Provincial Center for Disease Control and Prevention (CDC) (No. 2019025).

2.2. YLL rate calculation

We used YLL rate (YLL/100,000 population) as health outcome, which was adjusted by population size. The reason to use YLL rate is the effects of temperature on respiratory YLL may vary substantially across countries/regions due to the climate characteristics and long-term acclimation to local climate (Gasparrini et al. 2015). Moreover, YLL caused by non-optimal temperature among previous studies were not comparable because the size of YLL largely depends on population size of the studied setting. Therefore, YLL rate could increase the comparability between different regions in this study.

The population data used for YLL rate included the population size of total, male, females and two age groups (0–64 and ⩾65 years). For the locations in Yunnan, Guangdong, Hunan, Zhejiang and Jilin provinces, population data of each location were obtained from national or local Statistical Yearbooks from 2013 to 2017, and the annual average population size during the 5 years was used to calculate the YLL rate. For other locations, population data were collected from the sixth national population census conducted in 2010 (www.stats.gov.cn).

First, we collected original mortality data of 364 locations. Daily respiratory death records in the locations from Yunnan, Guangdong, Hunan, Zhejiang and Jilin provinces (from 1 January 2013 to 31
December 2017) were collected from the corresponding provincial CDC, while for other locations, daily respiratory mortality data (from 1 January 2006 to 31 December 2012) were obtained from China CDC (Ma et al 2015). Based on the International Classification of Diseases 10th Revision, we limited respiratory mortality to codes J00-J98. We also extracted specific-cause respiratory diseases including COPD (J44), pneumonia (J12-J18) and chronic LRTI (J40-J47).

Then we matched age and gender to the 2010 life tables of each province, which were derived from the sixth nationwide population census in 2010 (www.stats.gov.cn) to calculate individual YLL. The life tables of each province are provided in section 1.2 of appendix. After that, the daily total YLLs of respiratory death cause were calculated by summing the YLL for all respiratory deaths on the same day. We also calculated daily YLL by sex (males and female), age groups (0–64 and ≥65 years) and specific-cause of death (COPD, chronic LRTI and pneumonia). Finally, we calculated daily YLL rate (YLL/100 000 population) through dividing daily recorded YLL by corresponding population size.

2.3. Meteorological data
Daily meteorological data including daily mean temperature and relative humidity of 698 meteorological stations across China were derived from the China Meteorological Data Sharing Service System (http://data.cma.cn/). Then we employed thin plate spline smoothing software (ANUSPLIN) developed by the Australian National University to interpolate the daily temperature and relative humidity at a 0.01° × 0.01° resolution across China (section 1.3 and figure S1 in appendix) (Hutchinson 2013). We obtained the average daily temperature of the grids where each selected location overlapped.

2.4. Statistical analysis
2.4.1. Estimation of the associations of non-optimal temperatures with respiratory YLL rates
A two-stage approach was applied to examine temperature-YLL association in this study. At the first stage, location-specific temperature effects on daily respiratory YLL rate were estimated. We employed the distributed lag non-linear model (DLNM) with Gaussian distribution to estimate the associations of daily mean temperature with YLL rate in each location (Gasparrini et al 2010). The model is described as follows.

\[
\text{YLL}_t = \alpha + \text{bs}(\text{daily mean temperature}_t, \text{lag}) + \text{ns}(\text{daily relative humidity}_t) + \text{ns}((\text{time}_t, 7 \times \text{years}) + \beta_1 \text{DOW}_t) \tag{1}
\]

where \(t\) denotes the day of observation; \(\text{YLL}_t\) denotes the expected respiratory YLL rate on day \(t\), which was calculated by dividing the daily observed YLL by the total population size (/100 000) in each included location. Hence, the YLL rate introduced in the DLNM was the daily respiratory YLL in every 100 000 population. \(\alpha\) denotes the intercept indicating the baseline rate. A cross-basis function was introduced in the DLNM model, in which a quadratic B-spline (bs) with three internal knots placed at the 10th, 50th and 90th percentiles of location-specific daily mean temperature distributions was used to model the non-linear associations of temperature with YLL rate, and a natural cubic B-spline (ns) with an intercept and three internal knots placed at equally spaced values was used to model the lagged effects of temperature. Consistent with previous studies (Gasparrini et al 2015, Ma et al 2015), we used ns of relative humidity with 3 degrees of freedom (df) to exclude the confounding effects of relative humidity; time, \(t\) stands for the time variable to adjust for time trends, with 7 df yr\(^{-1}\); the day of the week is a dummy variable representing day of the week, and \(\beta_1\) is the coefficient. We used 21 d as the maximum lag period as suggested in previous studies (Gasparrini et al 2015, Ma et al 2015).

At the second stage, we employed a multivariate meta-analysis method to pool the location-specific association at regional and countrywide level, and then generated a best linear unbiased prediction (BLUP) for each location (Gasparrini et al 2015, Ma et al 2015). The BLUP approach makes use of a trade-off between location-specific relationship and the pooled average effect in the second stage, and thus provides more precise estimates for those locations with limited data of daily mortality.

The minimum YLL-rate temperature (MYT) and minimum YLL-rate percentile (MYP) were derived from the BLUP of pooled cumulative exposure-response relationship for each location, which were referred as the optimal temperature and corresponding percentile. The MYPs were used to re-center the quadratic B-spline of temperature in first stage analysis, and obtained accurate effect estimates at a given temperature in each location. And we separated temperature into four components (extreme cold, moderate cold, moderate heat, and extreme heat were defined as ≤2.5th percentile, 2.5th to the MYT, MYT to 97.5%, and >97.5% percentile of temperature, respectively).

2.4.2. Calculations of the average LLD of respiratory mortality
The average LLD of respiratory mortality caused by non-optimal temperatures was calculated using the following two equations (Majdan et al 2017):

\[
\text{LLD}_{\text{tem}} = \sum_{i=T\text{Min}}^{i=T\text{Max}} \text{YLL}' \ast \text{Freq} \tag{2}
\]

where, \(\text{LLD}_{\text{tem}}\) denotes the total lives lost of respiratory mortality attributable to non-optimal temperatures.
Table 1. General characteristics of study variables in 364 locations, China.

| Variable                        | Mean (SD) | Minimum | 25th percentile | Median  | 75th percentile | Maximum |
|---------------------------------|-----------|---------|------------------|---------|-----------------|---------|
| Daily respiratory YLL ratea     | 2.40 (4.00) | 0.00    | 0.00             | 1.18    | 3.36            | 595.40  |
| Sex                             |           |         |                  |         |                 |         |
| Male                            | 2.75 (5.83) | 0.00    | 0.00             | 0.00    | 3.74            | 679.92  |
| Female                          | 2.04 (5.46) | 0.00    | 0.00             | 0.00    | 2.55            | 1206.87 |
| Age (years)                     |           |         |                  |         |                 |         |
| 0–64                            | 0.69 (2.59) | 0.00    | 0.00             | 0.00    | 0.00            | 128.46  |
| ≥65                             | 18.55 (56.31) | 0.00    | 0.00             | 7.73    | 25.57           | 11 824.15 |
| Region                          |           |         |                  |         |                 |         |
| South China                     | 2.55 (4.19) | 0.00    | 0.00             | 1.42    | 3.57            | 595.40  |
| North China                     | 1.71 (4.01) | 0.00    | 0.00             | 0.00    | 2.12            | 182.41  |
| Disease                         |           |         |                  |         |                 |         |
| COPD                            | 0.87 (1.96) | 0.00    | 0.00             | 0.00    | 1.02            | 82.20   |
| Pneumonia                       | 0.51 (2.39) | 0.00    | 0.00             | 0.00    | 0.00            | 346.07  |
| Chronic LRTI                    | 1.65 (2.76) | 0.00    | 0.00             | 0.00    | 2.41            | 102.14  |
| Meteorological variables        |           |         |                  |         |                 |         |
| Daily mean temperature (°C)     | 15.9 (9.9) | −32.3   | 9.5              | 17.5    | 23.4            | 35.6    |
| Daily relative humidity (%)     | 72.4 (15.6) | 5.0     | 63.0             | 75.0    | 84.0            | 100.0   |

COPD: chronic obstructive pulmonary disease; LRTI: lower respiratory tract infection.

a YLL rate was the average YLL in every 100 000 population.

in every 100 000 population in a location. TMin denotes the minimum daily mean temperature, and TMax denotes the maximum daily mean temperature in the location. YLL’ denotes the YLL rate attributable to each temperature, which could be estimated by equation (1). Freq denotes the frequency of each temperature in the location.

\[ \text{LLD} = \frac{\text{LL}_{\text{tem}}}{N} \] (3)

Where \( \text{LL}_{\text{tem}} \) is calculated in equation (2), and \( N \) denotes the number of respiratory deaths in every 100 000 population in a study location.

2.4.3. Subgroup analyses
We conducted subgroup analyses stratified by gender, age (≥65 and 0–64 years old), region (south China and north China) and cause of death (COPD, chronic LRTI and pneumonia). Parameters were set by applying the same parameters in the main model.

2.4.4. Sensitivity analyses
Sensitivity analyses were performed using R software (version 3.5.0, R Foundation for Statistical Computing). R packages of ‘dlm’ and ‘mvmeta’ were mainly applied. For all statistical tests, two tailed \( P < 0.05 \) were considered as statistical significance.

3. Results

3.1. General characteristics of study sample
Table 1 shows the general characteristics of respiratory YLL rate (/100 000 population) and meteorological factors in 364 locations. The average temperature and relative humidity were 15.9 °C and 72.5%, respectively. The average daily respiratory YLL rate was 2.40/100 000, and the average daily YLL rates of COPD, pneumonia and chronic LRTI were 0.87/100 000, 0.51/100 000 and 1.65/100 000, respectively. Geographically, the average daily respiratory YLL rate was higher in south China (2.56/100 000) than north China (1.50/100 000) (table 1). The distribution of daily respiratory YLL rate is presented in figure S2.

3.2. Association between non-optimal temperature and respiratory YLL rate
Figure 1 shows inversely J-shaped cumulative exposure-response relationships between non-optimal temperature and respiratory YLL rate for overall population and the majority of subpopulations. The MYT was 26.9 °C (88.7th percentile) nationwide, and the MYTs for subgroups ranged from −6.4 °C in north China to 28.4 °C in south China (table 2).

The associations between non-optimal temperature and respiratory YLL rate were heterogeneous among subgroups. We observed greater effects of cold on respiratory YLL rates for males and the elderly...
Figure 1. Pooled cumulative exposure–response relationships between daily mean temperature and respiratory YLL rate over lag 0–21 d in all 364 locations and different subgroups across China. COPD: chronic obstructive pulmonary disease; LRTI: lower respiratory trait infection.

Table 2. Respiratory YLL rate for extreme cold and extreme heat in subgroups.

| Subgroups          | MYT  | MYT centile | Attributable YLL rate (100 000 population) |
|--------------------|------|-------------|-------------------------------------------|
|                    | MYT  | MYT centile | Extreme cold<sup>a</sup> | Extreme heat<sup>b</sup> |
| Overall            | 26.9 | 88.7        | 1.88 (1.53–2.24)           | 0.44 (0.27–0.60)        |
| Sex                |      |             |                            |                            |
| Male               | 26.8 | 87.3        | 2.45 (1.96–2.95)           | 0.34 (0.12–0.56)        |
| Female             | 12.4 | 33.7        | 1.34 (1.00–1.68)           | 0.55 (0.33–0.77)        |
| Age (year)         |      |             |                            |                            |
| 0–64               | 10.1 | 26.8        | 0.53 (0.38–0.69)           | 0.17 (0.05–0.29)        |
| ≥65                | 26.5 | 86.5        | 13.21 (10.70–15.73)        | 3.03 (2.00–4.06)        |
| Region             |      |             |                            |                            |
| South China        | 28.4 | 91.3        | 1.71 (1.41–2.00)           | 0.50 (0.31–0.68)        |
| North China        | −6.4 | 24.7        | 0.28 (0.10–0.46)           | 0.49 (0.02–0.96)        |
| Cause of death     |      |             |                            |                            |
| COPD               | 16.7 | 47.3        | 0.23 (0.17–0.28)           | 0.18 (0.14–0.23)        |
| Pneumonia          | 15.6 | 43.6        | 0.34 (0.21–0.46)           | 0.14 (0.06–0.22)        |
| Chronic LRTI       | 27.7 | 90.5        | 1.20 (0.96–1.44)           | 0.19 (0.08–0.30)        |

COPD: chronic obstructive pulmonary disease; LRTI: lower respiratory trait infection; MYT: minimum YLL temperature; MYP: minimum YLL percentile of the daily temperature

<sup>a</sup> extreme cold: 2.5 percentile of daily mean temperature distribution;

<sup>b</sup> extreme heat: 97.5 percentile of daily mean temperature distribution

(≥65 years old) compared with females and younger population (<65 years old), respectively. Respiratory YLL rates attributable to cold were greater in south China than that in north China, while reverse patterns were found for heat-attributed respiratory YLL rates. In addition, more pronounced effects were found for chronic LRTI than COPD and pneumonia.

Table 2 displayed the attributable respiratory YLL rates for extreme cold and extreme heat. Overall, extreme cold-related YLL rate (1.88/100 000, 95% CI: 1.53/100 000–2.24/100 000) was more significant than extreme heat-related YLL rate (0.44/100 000, 95% CI: 0.27/100 000–0.60/100 000). Similar patterns were identified in all subgroups except north China.
3.3. LLD of respiratory mortality attributed to non-optimal temperatures

The average LLD of respiratory mortality attributed to non-optimal temperature was 1.37 years (95% CI: 1.06–1.65) nationwide, most of which was attributed to moderate cold (0.73 years, 95% CI: 0.65–0.80) compared with extreme cold (0.16 years, 95% CI: 0.15–0.17). For heat, the average LLD was 0.49 years (95% CI: 0.18–0.77) nationwide, among which, 0.44 years (95% CI: 0.14–0.71) and 0.05 years (95% CI: 0.03–0.05) were attributed to moderate cold and heat, respectively.

In subgroup analysis, males (1.60 years, 95% CI: 1.21–1.98) had higher average LLD of respiratory mortality than females (1.30 years, 95% CI: 0.90–1.67). The average LLD of cold and heat for males was 1.10 years (95% CI: 0.96–1.23) and 0.61 years (95% CI: 0.61–0.77), respectively, while the average LLD of cold and heat were 0.69 years (95% CI: 0.61–0.77) and 0.16 years (95% CI: 0.15–0.17) for females (table 3). For the elderly, the average LLD of cold and heat were 1.00 years (95% CI: 0.91–1.10) and 0.37 years (95% CI: 0.18–0.59), and the corresponding average of LLD of cold and heat among the young (0–64 years old) was 1.45 years (95% CI: 1.24–1.65) and 2.62 years (95% CI: 1.33–3.92), respectively (table 3).

The average LLD of respiratory mortality attributable to non-optimal temperature in north China (2.83 years, 95% CI: 1.91–3.69) was higher than that in south China (1.35 years, 95% CI: 1.08–1.63). The average LLD of cold was larger in south China (1.03 years, 95% CI: 0.96–1.10) than that in north China (0.74 years, 95% CI: 0.41–1.06). Conversely, the average LLD of heat was much greater in north China (2.09 years, 95% CI: 1.22–2.93) than that in south China (0.32, 95% CI: 0.06–0.60) (table 3).

For specific-cause respiratory diseases, the average LLD was highest in pneumonia (2.06 years, 95% CI: 1.57–2.60), followed by chronic LRTI (2.03 years, 95% CI: 1.76–3.17) and COPD (0.88 years, 95% CI: 0.65–1.09) (table 3). Among which, the average LLDs of cold were larger than heat for pneumonia (1.29–1.63 years, 95% CI: 1.03–1.43 vs. 0.83 years, 95% CI: 0.37–1.37), chronic LRTI (1.69 years, 95% CI: 1.50–1.86 vs. 0.62 years, 95% CI: 0.55–0.69) and COPD (0.62 years, 95% CI: 0.55–0.69 vs. 0.26 years, 95% CI: 0.05–0.45) (table 3).

Related average LLDs among subgroups for temperature components are presented in figure 2.

3.4. Sensitivity analyses

Sensitivity analyses showed that the cumulative associations of non-optimal temperature with respiratory YLL rate were generally robust to the changes of df for the long-term trends, maximum lag days, federal holiday and knots placement (see figure S3).

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| Subgroups | Temperature | Cold | Heat | Extreme cold | Moderate cold | Extreme heat | Moderate heat |
|-----------|-------------|------|------|--------------|---------------|-------------|--------------|
| Overall   | 1.37        | 0.88 | 0.49 | 0.16         | 0.73          | 0.05        | 0.44         |
|           | (1.06–1.65) | (0.80–0.96) | (0.18–0.77) | (0.15–0.17) | (0.65–0.80) | (0.04–0.06) | (0.14–0.71) |
| Sex       |             |      |      |              |               |             |              |
| Male      | 1.60        | 1.10 | 0.50 | 0.17         | 0.93          | 0.04        | 0.46         |
|           | (1.21–1.98) | (0.96–1.23) | (0.15–0.89) | (0.16–0.18) | (0.80–1.05) | (0.03–0.05) | (0.12–0.84) |
| Female    | 1.30        | 0.69 | 0.61 | 0.13         | 0.56          | 0.06        | 0.55         |
|           | (0.90–1.67) | (0.61–0.77) | (0.23–0.97) | (0.12–0.15) | (0.48–0.63) | (0.05–0.07) | (0.17–0.90) |
| Age (Years) |           |      |      |              |               |             |              |
| 0–64      | 4.07        | 1.45 | 2.62 | 0.38         | 1.07          | 0.18        | 2.44         |
|           | (2.73–5.35) | (1.24–1.65) | (1.33–3.92) | (0.34–0.41) | (0.89–1.25) | (0.13–0.22) | (1.20–3.72) |
|           | 1.37        | 1.00 | 0.37 | 0.13         | 0.87          | 0.04        | 0.33         |
|           | (1.16–1.60) | (0.91–1.10) | (0.18–0.59) | (0.12–0.14) | (0.78–0.96) | (0.03–0.05) | (0.14–0.54) |
| ≥65       |             |      |      |              |               |             |              |
| Region    |             |      |      |              |               |             |              |
| South     | 1.35        | 1.03 | 0.32 | 0.16         | 0.87          | 0.04        | 0.28         |
|           | (1.08–1.63) | (0.96–1.10) | (0.06–0.60) | (0.15–0.17) | (0.81–0.94) | (0.03–0.05) | (0.03–0.55) |
| North     | 2.83        | 0.74 | 2.09 | 0.18         | 0.56          | 0.16        | 1.93         |
|           | (1.91–3.69) | (0.41–1.06) | (1.22–2.93) | (0.14–0.22) | (0.26–0.85) | (0.13–0.20) | (1.09–2.73) |
| Cause of death | | | | | | | |
| COPD      | 0.88        | 0.62 | 0.26 | 0.10         | 0.52          | 0.02        | 0.24         |
|           | (0.65–1.09) | (0.55–0.69) | (0.05–0.45) | (0.09–0.11) | (0.46–0.59) | (0.01–0.03) | (0.04–0.42) |
| Pneumonia | 2.06        | 1.23 | 0.83 | 0.18         | 1.05          | 0.09        | 0.74         |
|           | (1.57–2.60) | (1.03–1.43) | (0.37–1.37) | (0.16–0.21) | (0.87–1.23) | (0.07–0.11) | (0.3–1.27)  |
| Chronic   | 2.03        | 1.69 | 0.34 | 0.22         | 1.47          | 0.04        | 0.30         |
|           | (1.76–3.21) | (1.5–1.86) | (0.15–0.54) | (0.2–0.23) | (1.29–1.63) | (0.04–0.05) | (0.11–0.49) |

COPD: chronic obstructive pulmonary disease; LRTI: lower respiratory tract infection
4. Discussion

Our study, using YLL rate as health outcome, identified a significant impact of non-optimal temperature on respiratory mortality. We observed a pooled inversely J-shaped temperature-YLL rate relationship, indicating that both low and high non-optimal temperatures were associated with increased respiratory YLL rate. More importantly, our study first reported the average LLD of respiratory mortality caused by non-optimal temperature. An average of 1.37 years of LLD was attributed to non-optimal temperature, among which moderate temperature, especially moderate cold was responsible for the majority of LLD.

Studies assessing non-optimal temperature-YLL relationship are scarce, especially for respiratory YLL (Yang et al. 2015, Luan et al. 2017, Zhang et al. 2018). A provincial analysis with 12 communities found heat but not cold effect was significant for respiratory YLL. But all the previous studies were conducted in single city (Yang et al. 2015, Luan et al. 2019) or at provincial level (Zhang et al. 2018), and used YLL but not YLL rate as outcome, which makes it difficult to compare the results of different studies.

Using death count as a health outcome, Gasparini et al found substantial differences between countries (Gasparini et al. 2015). But similar pattern with our study was observed in association between non-optimal temperature and death counts in 272 cities of China (Chen et al. 2018). The findings implied that we should not only focus on the health impact of extreme weather, but also moderate temperature, especially moderate cold should be considered in respiratory mortality prevention.

Previous studies suggested that gender might be a potential effect modifier in non-optimal temperature-mortality relationship (Zhang et al. 2018). The higher LLD in males observed in the current study might be due to biological difference between males and females (Yang et al. 2015). For example, males have larger decreases in core body temperature, and experience larger immune response when expose to cold (Solianik et al. 2014), which could exacerbate chronic respiratory diseases (Halonen et al. 2010). In addition, the life expectancy of males was lower than females (2018a), which could result in higher YLL rate.

Zhang et al. suggested higher respiratory mortality risk attributable to temperature for the elderly (≥65 years) than the young (0–64 years) (Zhang et al. 2018). However, we observed larger LLD for the young. This difference indicates that respiratory mortality burden attributable to non-optimal temperatures was heavier for each young death, though the absolute number of respiratory deaths due to non-optimal temperatures were smaller than the elderly. Individuals dying at younger age would suffer from more YLL compared with the elderly, it could partially explain the difference we observed.

In terms of regional heterogeneity, we found much lower cold effects in north China than south China. The reasons for this may be related to cold adaption and central heating system in winter in north China. In addition, our study observed much higher heat-related LLD in north China, which is consistent with a YLL analysis including 12 communities in Hubei province, which locates in north China (Zhang et al. 2018). This finding could be due to the
much lower MYT in north China than that identified in south China, which caused some low temperatures to be classified into heat, therefore hot days accounting for a high proportion.

Three major cause-specific respiratory diseases including COPD, chronic LRTI and pneumonia contributed to a large proportion of temperature-related respiratory YLL rate. Like total respiratory mortality, the LLDs of cause-specific respiratory attributed to cold were significantly higher than that of heat. Similar pattern was previously identified in COPD YLL of 31 Chinese cities separately (Luan et al 2019). These findings imply that populations with COPD, chronic LRTI and pneumonia are much vulnerable to cold temperatures. Greater efforts should be taken to enhance the patients’ understanding of temperature-respiratory relationships; in addition, in cold days populations with COPD, chronic LRTI or pneumonia should limit outdoor activities and pay attention to indoor heating.

To our knowledge, this is the largest study investigating non-optimal temperature-related respiratory mortality measured by YLL rate, and we used data in a relatively long-time span across China with significant temperature variations. Secondly, we applied a population adjusted YLL rate (YLL/100 000 population) as outcome, which made it possible to pool the exposure–response relationships from multiple locations, and could facilitate the comparison in the effects between regions. Additionally, as far as we know, we are the first to estimate the average LLD which could help the general public understand the magnitude of the problem easily, and raise awareness of health effect of climate change one step further.

Some limitations should be mentioned in the present study. First, the model did not control for air pollution as confounding factors because air pollution surveillance data was not available for more than 200 out of the 364 locations. However, it has been demonstrated that adjusting for air pollution did not change the association of temperature and mortality substantially (Xie et al 2013, Chen et al 2018). Secondly, due to the limited available locations in north China, it is difficult to split our sample into more subregions. Thirdly, we tried to separate cause-specific YLLs by gender, age and region, but because in a large proportion of days the daily YLLs equals to zero in some subgroups, the model cannot converge, therefore we did not report cause-specific YLL rates by gender, age and region in this study. Last but not least, because of limited data availability, we did not control confounding factors such as health service condition and infectious disease, which should be considered in the future.

5. Conclusions

In summary, exposure to non-optimal temperature increases respiratory YLL rate in China, most of which were attributed to moderate cold. People suffers from respiratory diseases including pneumonia, chronic LRTI and COPD are vulnerable to non-optimal temperature exposure. The result of this study provides useful information to reduce temperature-related respiratory disease burden.

Data availability statement

Meteorological data can be accessed from the China Meteorological Data Sharing Service System (http://data.cma.cn/). The mortality data of this study are available from the corresponding author (mawj@gdiph.org.cn), upon reasonable request. The data are not publicly available due to the information that could compromise the personal privacy.

The data that support the findings of this study are available upon reasonable request from the authors.

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Conflict of interest

The authors have no conflict of interest to declare.
Ethics approval

The study was approved by the Ethics Committee of Guangdong Provincial Center for Disease Control and Prevention (2019025).

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