Extreme temperatures and emergency department admissions for childhood asthma in Brisbane, Australia

Zhiwei Xu,1 Cunrui Huang,2 Wenbiao Hu,3 Lyle R Turner,1 Hong Su,4 Shilu Tong1

ABSTRACT

Objectives To examine the effect of extreme temperatures on emergency department admissions (EDAs) for childhood asthma.

Methods An ecological design was used in this study. A Poisson linear regression model combined with a distributed lag non-linear model was used to quantify the effect of temperature on EDAs for asthma among children aged 0–14 years in Brisbane, Australia, during January 2003–December 2009, while controlling for air pollution, relative humidity, day of the week, season and long-term trends. The model residuals were checked to identify whether there was an added effect due to heat waves or cold spells.

Results There were 13 324 EDAs for childhood asthma during the study period. Both hot and cold temperatures were associated with increases in EDAs for childhood asthma, and their effects both appeared to be acute. An added effect of heat waves on EDAs for childhood asthma was observed, but no added effect of cold spells was found. Male children and children aged 0–4 years were most vulnerable to heat effects, while children aged 10–14 years were most vulnerable to cold effects.

Conclusions Both hot and cold temperatures seemed to affect EDAs for childhood asthma. As climate change continues, children aged 0–4 years are at particular risk for asthma.

INTRODUCTION

Asthma is one of the most frequent chronic childhood illnesses worldwide.1 It was the most common of the five most frequently reported long-term conditions among Australian children aged 0–14 years in 2007–2008,2 and will continue to be a major cause of disease burden in Australia over the next two decades.2 Currently, there is no cure for asthma, so it is particularly important to identify potential risk factors and vulnerable subgroups, in order that targeted control and prevention strategies can be developed. Although the aetiology of asthma has not been fully elucidated, there is evidence that environmental factors may trigger asthma attacks.3–5 Previous studies have found an inverse association between monthly ambient temperatures and hospital admissions for asthma in different regions.6–7 However, little is known about the impact of extreme temperatures on childhood asthma.

Persistent extreme temperatures (ie, heat waves and cold spells) have been found to adversely affect mortality and morbidity.8–10 Some studies have found that the effects of persistent extreme temperatures on human health are due to the independent effects of ambient daily temperature (main effect) and of sustained periods of heat and cold (added effect).8 11 12 Recently, Guo et al13 found a significant relationship between cold spells and paediatric outpatient visits for asthma in Shanghai, China. However, to the best of our knowledge, to date, no studies have specifically examined whether the increased risk of childhood asthma during extreme temperature periods is due to the main effect of daily temperature fluctuations and/or the added effect of persistent extreme temperatures.

There is a need to systematically explore the impacts of daily extreme temperatures and of consecutive days of extreme temperatures on childhood asthma occurrence. This study attempted to answer three questions: (1) what is the relationship between extreme temperatures and emergency department admissions (EDAs) for childhood asthma? (2) is there any added effect due to heat waves and cold spells? and (3) which subgroups are most vulnerable to the effects of extreme temperatures?
MATERIALS AND METHODS

Study design
An ecological design was used in this study to assess the impact of extreme temperatures on daily EDAs for childhood asthma.

Data collection
Brisbane is the state capital of Queensland, located on the east coast of Australia. It has a subtropical climate, with mild winters and hot summers. Children aged 0–14 years account for 18% of the residential population in Brisbane.14

Electronic medical records containing EDA data for Brisbane from 1 January 2003 to 31 December 2009 were retrieved from Queensland Health. The EDA data were classified according to the International Classification of Diseases, 10th revision (ICD-10) and those coded as asthma (J45) in children aged 0–14 years were selected. Daily weather data for the same period, including maximum temperature, minimum temperature and relative humidity, were provided by the Australian Bureau of Meteorology. Daily mean temperature was calculated by averaging the daily maximum and minimum temperatures. Air pollution data, including daily average particulate matter ≤10 μm (PM10, μg/m³), daily average nitrogen dioxide (NO2, μg/m³) and daily average ozone (O3, ppb) levels, were obtained from the Queensland Department of Environment and Heritage Protection.

Heat wave and cold spell definitions
To date, there are no standard definitions for either heat waves or cold spells, mainly because of variations in population characteristics and individual adaptation capability.15 16 In this study, we identified heat waves and cold spells according to temperature intensity and duration: (1) the 5th and 6th percentiles of daily mean temperature were defined as the cold threshold, and the 95th and 96th percentiles of the daily mean temperature as the heat threshold; and (2) a minimum of 2–4 consecutive days with temperatures below the cold threshold or above the heat threshold were required.

Data analysis
Stage I: estimating the main temperature effects
A Poisson generalised linear regression model combined with a distributed lag non-linear model (DLNM) was used to estimate the association between temperature and EDAs for childhood asthma. As the relationship between temperature and morbidity has been reported to be non-linear,17 a natural cubic spline with 5 degrees of freedom (df) was used to capture the non-linear temperature effects. Previous studies have reported that there is a lagged effect of temperature on morbidity,18 19 so we plotted a three-dimensional figure of temperature effect on EDAs for childhood asthma, which simultaneously incorporated non-linear exposure–response relationships and lagged effects.

Stage II: examining the added effects of heat waves and cold spells
Previous studies have documented that sustained periods of heat and cold could produce an added effect on mortality independent of daily temperature effects.11 12 We analysed the residuals of the stage I model to examine the potential added effects of heat waves and cold spells. At stage II, we estimated the added effects of heat waves and cold spells after removing the main effects of temperature. We assumed a maximum lag of 21 days for the delayed effects of heat waves and cold spells. EDAs for childhood asthma on extreme temperature days were compared with those on non-extreme temperature days.

RESULTS

Characteristics of weather variables, air pollutants and daily EDAs for childhood asthma
The summary statistics for weather variables, air pollutants and EDAs for age- and gender-specific childhood asthma are given in table 1. The average mean temperature and relative humidity were 20.6°C and 57.3%, respectively. The average values for O3, PM10 and NO2 were 12.6 ppb (range: 1.7–31.6), 16.0 μg/m³ (4.4–35.5)2 and 7.0 μg/m³ (3.8–25.3), respectively. There were 13324 EDAs for childhood asthma in Brisbane over the study period. Among these EDAs, 8230 were males and 5094 were females. 8643 were children aged 0–4 years, 3398 were children aged 5–9 years and 1283 were children aged 10–14 years. The mean daily number of EDAs for asthma among children aged 0–4 years (3.4) was greater than among children aged 5–9 years (0.5).

Figure 1 illustrates the daily distribution of EDAs for childhood asthma in Brisbane over the study period, indicating a seasonal pattern. Figure 2, which shows the monthly distribution of childhood asthma, reveals that childhood asthma was more prevalent in the months of February, May, June and July than in other months in Brisbane.

Association between temperature and EDAs for childhood asthma

Figure 3 shows the exposure–response relationship between daily mean temperature and EDAs for childhood asthma for different lag periods. It clearly shows that both cold and hot temperature had significant effects on EDAs for childhood asthma, and their effects occurred on the same day as exposure. Extremely high temperatures had a particularly large effect on EDAs for childhood asthma, although the effect of extremely high temperatures was found in a region with few data points.

Figure 3 also shows that, for lag 0, the risks of cold temperature decreased slightly when the temperature was below the 5th percentile.

Table 2 shows the effects of high and cold temperatures at several lags, revealing that male children and children aged 0–4 years were particularly sensitive to hot temperature, and children aged 10–14 years were particularly sensitive to cold effect. The fact that hot temperatures had a greater effect than cold temperatures is indicated in figure 3 but appears not to be reflected in table 2. This is mainly because the greatest effect of heat is observed far above the 95th percentile, which is what is reported in table 2. Further, in table 2, the magnitude of hot and cold temperature effects on childhood asthma appeared to be greatest at lag 0–21 days because of the cumulative effect estimate we reported. In fact, the shortest lags are the most important and the effects of both hot and cold temperatures were acute.

Added effects of heat waves and cold spells

Table 3 shows the daily excess EDAs for childhood asthma on heat wave days and cold spell days as opposed to non-heat wave days and non-cold spell days. Using a heat wave definition of 2 days with the temperature over the 95th or 96th percentile, we found there was not a significant increase in EDAs for childhood asthma in heat waves. However, using a heat wave definition of 3 days with the temperature over the 95th or 96th percentile, we found there were significant increases in EDAs for childhood asthma in heat waves. There was no significant increase in EDAs for childhood asthma during cold spells.

Sensitivity analysis results

To conduct the sensitivity analysis, we changed the degrees of freedom (8–15 per year) for time to control for season. We also altered the degrees of freedom (5–7) for temperature and humidity. Further, we changed the definitions of high temperature (27.8°C, 99th percentile of mean temperature) and cold temperature (11.9°C, 1st percentile of mean temperature) for use in comparison with the reference temperature (24°C) and estimation of the relative risk of EDAs for childhood asthma. The results were similar (results not shown).
DISCUSSION

In recent years, the public health literature has increasingly recognised that extreme temperatures have a significant health impact on paediatric respiratory diseases.\(^2^1\) This study assessed the effects of extreme temperatures on EDAs for childhood asthma, and explored the added effects of heat waves and cold spells. The results suggest that both hot and cold temperatures were significantly associated with increases in EDAs for childhood asthma in Brisbane. Lagged effects of heat and cold on EDAs for childhood asthma were observed. Male children and children aged 0–4 years were particularly vulnerable to heat, while children aged 10–14 years were more sensitive to cold. Statistically significant added effects of heat waves were observed, with seven to eight EDAs for childhood asthma per day depending on the severity of the heat wave, although the findings were mainly based on only 1 or 2 days of data.

Temperature can directly influence childhood asthma by affecting inflammation pathways or airway hyper-responsiveness.\(^2^2\) In addition, temperature may also indirectly affect asthma triggers, such as viral infections,\(^2^3\) bacterial activity,\(^2^4\) the growth of indoor allergens\(^2^5\) and time spent outdoors. This study found cold temperature was significantly associated with an increase in EDAs for asthma, which corresponds to previous findings from China, Canada and the USA.\(^1^3\)\(^,\)\(^2^2\)\(^,\)\(^2^6\) The effect of cold temperature on childhood asthma may be due to the fact that low temperatures facilitate bacterial survival in water droplets\(^2^4\) and encourage cross-infection from crowding indoors. The literature has documented that abrupt cooling of air enhances inflammation and thereby causes airway narrowing and exacerbates asthma.\(^2^7\) To date, however, very few studies have found adverse effects of high temperature on childhood asthma.\(^2^8\) Higher temperatures can enhance the growth of indoor allergens, such as moulds, mites and cockroaches,\(^2^4\) which play a role in the occurrence of asthma. Differing pollution patterns in summer and winter indicate that levels of pollutants such as \(O_3\) and PM\(_{10}\) may be higher in hot weather.\(^2^9\) Direct and interaction effects of pollutants on asthma are therefore more likely to be experienced in summer periods, particularly as children often engage in outdoor activities. It is very important to determine how high temperature influences asthma, because the burden of asthma is expected to increase in many developed countries\(^3^0\) and the
average global surface temperature is projected to rise over the coming decades.31

Understanding the lag pattern of heat and cold effects is essential for the policy makers and community leaders who develop response plans for periods of extreme temperatures. Interestingly, in this study we found that both heat and cold had acute effects. Previous studies investigating the effects of extreme temperatures on morbidity found that cold effects are not acute and last longer than heat effects.32 This inconsistency can be partially explained by the different mechanisms of cold effects on asthma. The temperature of exhaled breath has been found to be a biomarker for asthma33 and may cause acute effects. The temperature of exhaled breath can be partially explained by the different mechanisms of cold effects on asthma. The temperature of exhaled breath has been found to be a biomarker for asthma33 and may cause acute effects. Previous studies investigating the effects of extreme temperatures on morbidity found that cold effects are not acute and last longer than heat effects.32

Table 2 The effects of hot and cold temperatures on emergency department admissions for childhood asthma, with the 95th percentile (26.5°C) and the 5th percentile (13.8°C) of temperature relative to the reference temperature (24°C).

<table>
<thead>
<tr>
<th>Children category</th>
<th>Heat effect relative risk (95% CI)</th>
<th>Cold effect relative risk (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lag 0–1 days</td>
<td>Lag 0–13 days</td>
</tr>
<tr>
<td>All ages</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0–4 years</td>
<td>1.12 (1.02 to 1.22)*</td>
<td>1.53 (1.19 to 1.95)*</td>
</tr>
<tr>
<td>5–9 years</td>
<td>1.17 (1.06 to 1.29)*</td>
<td>1.61 (1.22 to 2.14)*</td>
</tr>
<tr>
<td>10–14 years</td>
<td>0.93 (0.79 to 1.10)</td>
<td>1.13 (0.72 to 1.76)</td>
</tr>
<tr>
<td>Male</td>
<td>1.12 (0.89 to 1.42)</td>
<td>1.61 (0.84 to 3.11)</td>
</tr>
<tr>
<td>Female</td>
<td>1.13 (1.02 to 1.25)*</td>
<td>1.63 (1.22 to 2.20)*</td>
</tr>
<tr>
<td>10 years</td>
<td>1.08 (0.95 to 1.23)</td>
<td>1.37 (0.97 to 1.96)</td>
</tr>
</tbody>
</table>

*p<0.05.

Table 3 Emergency department admissions for asthma due to the added effect of heat waves and cold spells in Brisbane, Australia, 2003–2009.

<table>
<thead>
<tr>
<th>Number of consecutive days</th>
<th>Heat waves</th>
<th>Cold spells</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Percentile*</td>
<td>Days†</td>
</tr>
<tr>
<td>≥2</td>
<td>≥95th</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>≥96th</td>
<td>7</td>
</tr>
<tr>
<td>≥3</td>
<td>≥95th</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>≥96th</td>
<td>1</td>
</tr>
<tr>
<td>≥4</td>
<td>≥95th</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>≥96th</td>
<td>0</td>
</tr>
</tbody>
</table>

*The threshold cut-off which we used to define heat waves and cold spells.
†The number of heat wave and cold spell days.
‡The daily number of emergency department admissions for childhood asthma due to heat waves or cold spells.
the findings. Fourth, the relatively fewer admissions of children aged 10–14 years may reduce the power to detect a significant association.

CONCLUSIONS
The impact of climate change on children’s health has received limited attention to date. This study contributes to understanding of the effect of extreme temperatures on EDAs for childhood asthma. It found strong evidence that both heat and cold were significantly associated with an increase in EDAs for childhood asthma, and also that there is an added effect of heat waves on EDAs for asthma. Childhood asthma control and prevention strategies should focus more on male children and children aged 0–4 years on hot days, especially prolonged hot weather.

Acknowledgements
We would like to thank Xiaofang Ye and Jiajia Wang for their valuable comments on an early draft.

Contributors
ZX and ST designed the study. ZX analysed the data and wrote the first draft. ST, CH, WH, LRT and HS contributed to manuscript revision.

Funding
ZX is funded by a China Scholarship Council Postgraduate Scholarship, a Queensland University of Technology fee waiving scholarship, and the CSIRO Climate Adaptation Flagship Collaboration Fund; ST is supported by a National Health and Medical Research Council Research Fellowship (#553043).

Competing interests
None.

Provenance and peer review
Not commissioned; externally peer reviewed.

REFERENCES
Extreme temperatures and emergency department admissions for childhood asthma in Brisbane, Australia

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*Occup Environ Med* 2013 70: 730-735 originally published online July 24, 2013
doi: 10.1136/oemed-2013-101538

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