Environmental Research 135 (2014) 15–20

Contents lists available at ScienceDirect

Environmental Research

journal homepage: www.elsevier.com/locate/envres

Outdoor temperature changes and emergency department visits for asthma in Seoul, Korea: A time-series study

Jayeun Kim [a], Younhee Lim [b], Ho Kim [a,b,*]

[a] Department of Biostatistics and Epidemiology, School of Public Health, Seoul National University, 1 Gwanak-Ro, Gwanak Gu, Seoul 151-752, Republic of Korea
[b] Institute of Health and Environment, Seoul National University, Seoul, Republic of Korea

ARTICLE INFO

Article history:
Received 7 April 2014
Received in revised form
2 July 2014
Accepted 4 July 2014

Keywords:
Asthma
Diurnal temperature range
Emergency
Temperature change
Time-series

ABSTRACT

Background: Extreme temperatures and temperature changes are known indicators of climate change, and large temperature variations for several consecutive days may affect human health such as exacerbating respiratory symptoms. The objective of this study was to determine the association between outdoor temperature change and asthma-related emergency department visits. In particular, this study examined seasonality and identified susceptible populations, such as the elderly.
Methods: The health data for asthma-related emergency department visits were collected from July 1, 2007, to December 31, 2010 in Seoul, Korea, through the National Emergency Department Information System of the National Emergency Medical Center and we defined temperature change as the absolute difference of mean temperature between the current day and the previous day. We applied generalized linear models with an allowance of over-dispersion for quantifying the estimated effects of temperature change on asthma-related emergency department visits, adjusting for meteorological conditions, air pollution, and time trend.
Results: In general, temperature change was adversely associated with asthma-related emergency department visits, with a 1-unit increase of temperature change associated with a 3.5% (95% CI 0.7, 6.4%) increase in emergency department visits. In addition, seasonal variation after adjusting for mean temperature and diurnal temperature range had an adverse effect in spring, summer, and fall and a protective effect in winter. Patients aged ≥ 65 years experienced the most prominent effect during the fall, with a 17.9% (95% CI 4.1, 33.6%) increase in emergency department visits per 1-unit increase of temperature change, whereas the other seasons showed no statistically significant association.
Conclusions: Along with diurnal temperature range, temperature change may be an alternative indicator of climate change. Temperature change variables are well-known and easy to communicate with the public relative to the health effects of outdoor temperature fluctuations.

1. Introduction

Asthma is a major public health problem, and studies have documented the underlying causes of asthma to be viral infections (Carroll and Hartert, 2008; Murphy et al., 2013; Wark et al., 2013), air pollution (Kim et al., 2007; Lewis et al., 2013; Ruffoni et al., 2013; Zora et al. 2013; Delfino, et al. 2014), and ambient temperature (Buckley and Richardson, 2012; Kim et al., 2012). Many studies have shown that outdoor temperature is associated with mortality (Yang et al., 2012; Wu et al., 2013), and to date, studies on temperature have been extended from extreme temperature to include temperature change. In consideration of temperature change, diurnal temperature range (DTR) represents temperature change calculated as the difference between maximum and minimum temperature in a given day. DTR has been shown to be positively associated with nonaccidental and cardiovascular mortality (Tam et al., 2009; Lim Park et al., 2012) and respiratory mortality (Kan et al., 2007; Lim et al., 2013).

However, mortality or morbidity associated with temperature change cannot be fully explained by the DTR. Daily maximum temperature usually occurs between 1300 and 1600 h, and the minimum temperature occurs at dawn, just before the sun rises. Accordingly, the DTR covers dawn to mid-afternoon, leaving the effects of evening and nighttime temperatures unaccounted for. Furthermore, because nocturnal minimum temperatures rise faster

Abbreviations: TC, temperature change an absolute difference of daily mean temperature between a given day and the previous day; TCN, temperature change between neighboring days

* Corresponding author. Fax: +82 2 745 9104.
E-mail addresses: kimjayeun@gmail.com (J. Kim), limyounhee@gmail.com (Y. Lim), hokim@snu.ac.kr (H. Kim).

http://dx.doi.org/10.1016/j.envres.2014.07.032
0013-9351/

than daytime maximum temperatures, the DTR is decreasing in the context of global climate change in most regions of the world (Easterling et al., 1997; Vose et al., 2005).

Another concept in temperature change studies is that of temperature changes occurring between neighboring days (TCN), which is calculated as the current day's mean temperature minus the previous day's mean temperature (Guo et al., 2011; Lin et al., 2013). TCN has been shown to be adversely associated with cardiovascular mortality (Guo et al., 2011; Lin et al., 2013) and nonaccidental mortality during the summer alone (Lin Zhang et al., 2013), but a few studies on morbidity have shown a negligible association of 24-h temperature change on asthma-related emergency department (ED) visits among children (Wasilevich et al., 2012). TCN has been shown to have a protective effect for nonaccidental and cardiovascular mortality (first to fifth percentile, -3.6 °C to -2.3 °C) (Lin et al., 2013), but TCN has both a minus and a plus value, which makes interpretation of outcomes difficult to communicate with the public. For efficient communication, we introduce a simpler term of temperature change that represents an absolute difference of daily mean temperature between a given day and the previous day (TC).

We hypothesized that TC has an adverse influence on health during periods when temperature variation is wide for several consecutive days compared with during days with less variation because of thermal stress to the human body (Martens, 1998) and that susceptibility to extreme temperature changes differ by individual characteristics (Gouveia et al., 2003; Kim and Joh, 2006; Basu and Ostro, 2008). Furthermore, people with asthma may be at more risk for an exacerbation when they experience larger outdoor temperature changes for several days. The objective of this study was to determine the association between outdoor temperature changes (i.e., TC) and asthma-related ED visits. In particular, we examined the seasonal relationship of TC among patients and analyzed the effect size by age group.

2. Materials and method

2.1. Health data

ED data were collected from July 1, 2007, to December 31, 2010, through the National Emergency Department Information System (NEDIS) of the National Emergency Medical Center. The National Emergency Medical Center has been collecting nationwide ED visit information since 2005, with the number and scope of hospitals enrolled into the system stabilized by mid 2007. NEDIS were incorporated with 137 hospitals in 7 metropolitans and 9 provinces and out of 31 hospitals participated in Seoul, we used 29 hospitals' ED visit information in the analysis, and these hospitals were constantly enrolled to the system since 2007. An asthma-related ED visit was defined as that resulting in any diagnosis of asthma at discharge from the ED (Korean Classification of Diseases, 5th and 6th editions, code J45), and all ages were enrolled during the study period; the study area was confined to Seoul. Due to unavailable residential address information for ED patients, we used 29 hospital locations confined in Seoul Metropolitan as proxies for patient addresses. For each asthma-related ED visit, the following variables were collected from the NEDIS data: date of ED visit, ED discharge diagnosis, sex, and age. From the date of ED visit, the following categorical variables were created: holiday, day of week, month, and season. During the study period, all national holidays were categorized in Sunday, and season was defined as spring (March–May), summer (June–August), fall (September–November), or winter (December–February). This study was exempt from approval by the Institutional Review Board of Seoul National University, School of Public Health (IRB no. 64-2013-12-04).

2.2. Weather and air pollution data

Weather data, including daily mean temperature (°C), relative humidity (%), and air pressure (hPa) were obtained from the Korean Meteorological Administration and recorded based on a period of 1–24 h within a single day. DTR was calculated as the difference between daily minimum and maximum temperatures, and TC was calculated as the absolute difference of mean temperature between the current day and the previous day [$TC_t = |\text{Temperature}_t - \text{Temperature}_{t-1}|$, t = ED visit date] where t is the day of ED visits and $t-1$ is the day before ED visits. Hourly concentrations for particulate matter ≤ 10 μm in aerodynamic diameter (PM_{10}) and ozone (O_3) (parts per billion [ppb]) were collected from the National Institute of Environmental Research and we averaged hourly concentrations into daily mean. If two or more monitoring stations were located in the city, averages of PM_{10} and O_3 exposure were calculated.

2.3. Statistical analysis

Descriptive analyses were used to assess the distribution of age at visit, sex, and temporal characteristics of the visit (i.e., year, season, day of week(DOW)). Poisson generalized linear regression models with allowance of over-dispersion were used to quantify the effect of mean temperature, DTR, and TC for asthma-related ED visits. All exposure variables (mean values for O_3, PM_{10}, temperature, relative humidity, and air pressure) were treated as continuous variables and controlled for in the model. We also controlled for national holidays and Sundays because both private and public ambulatory clinics are closed on these days, so people with acute illness must visit the ED on these days. Mean temperature and long-term trends were controlled for with natural cubic splines with 7 and 16 degrees of freedom (df), respectively; accordingly, long-term trends have 4 df per year. In making a decision on df, a sensitivity analysis was used to test DTR and TC effects by changing the df for temperature from 1 to 15 and the df for time trend from 1 to 50 to acquire conservative estimates of each effect by inadequate controlling for the temperature and time trend. Day of week and national holidays and Sundays were treated as categorical variables. We considered the lag effects of weather conditions and pollutant concentrations in building the models because weather conditions and air pollution levels on the current day and several preceding days affect the number of ED visits on a given day. We considered moving average lag structures defined as a multiday average from lag01 to lag010. For example, lag01 is the 2-day moving average of the current and previous days' values. However, based on the definition of TC, lag01 for TC is the average of mean temperature difference between the current day and the previous day and the mean temperature difference between the previous day and the day before that. For example, we obtained TC's lag05 value using this formula $\left(TC_{lag05} = \Sigma_{t=0}^{5}(TC_t/5+1)\right)$ and TC_{lag05} is TC's 6 days moving average from the current (t=0) to previous 5 consecutive days (t=1, 2, 3, 4, 5) and TC_t is temperature change on t day. Because of the nonlinear relationship between asthma-related ED visits and temperature, we applied a two-part model using R package *HEAT* (Lim and Kim, 2013) to estimate a threshold point. We also conducted an analysis to identify seasonal patterns and susceptible age groups. All results for the effect of mean temperature, DTR, and TC are expressed as percent increases in ED visits per 1 °C increase, and all procedures were conducted using R version 3.0.2 (The Comprehensive R Archive Network: http://cran.r-project.org).

3. Results

Table 1 shows the characteristics of asthma-related ED visits. During the study period from July 1, 2007, to December 31, 2010, the number of asthma-related ED visits in Seoul was 16,509 (8833 [53.5%] and 7676 [46.5%] for male and female patients, respectively). During this time, the resident population in Seoul was approximately 10 million, with this number increasing slightly but not significantly (resident population in Seoul, 10,192,710 on the year 2007 and 10,312,545 on the year 2010 from Korea National Statistics Office). The number of ED visits by age group was 3885 (23.5%) for patients aged ≥ 65 years. The number of asthma-related ED visits varied by season ($X^2 = 981.9$, $P < 0.001$) as follows: spring (3848 [23.3%]), summer (3061 [18.5%]), fall (5783 [35.0%]), and winter (3817 [23.1%]). The number of ED visits peaked on Sundays ($X^2 = 440.3$, $P < 0.001$).

Table 2 shows the descriptive statistics of daily asthma-related ED visits, meteorological measures, and air pollutant concentrations by season. The daily mean number of asthma-related ED visits ranged from 9.1 to 15.9. Mean DTR was highest in spring (8.7 °C) and lowest in summer (6.8 °C), and mean TC was highest in winter (2.4 °C) and lowest in summer (1.3 °C). Mean temperature and mean relative humidity were highest during the summer, PM_{10} levels ranged from 40.3 μg/m^3 (summer) to 63.9 μg/m^3 (winter), and O_3 levels ranged from 14.5 ppb (winter) to 34.2 ppb (spring).

Fig. 1 shows the exposure–response relationships between mean temperature, DTR, and TC and asthma-related ED visits at the greatest day lag (lag05) after controlling for confounders. For the time-series analysis, we constructed three models with various combinations of these variables: (1) mean temperature, DTR, and TC; (2) mean temperature and DTR; and (3) mean temperature and