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Effects of Air Pollution on Asthma Hospitalization Rates in Different Age Groups in Metropolitan Cities of Korea

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Abstract

Many studies have shown associations between air pollution and asthma admissions in Korea, but have not reported whether these effects differ by age classification. The purpose of this study was to determine whether air pollution effects on asthmatic hospital admissions are different by three age groups (years): children (less than 15), adults (15–64; reference group), and the elderly (over 65). Daily time-series data from seven metropolitan cities in South Korea were analyzed in two stages. In the first stage, relative asthma morbidity rates associated with air pollution were estimated for each city and age group, using semi-parametric log-linear regression. In the second stage, estimates from all seven cities were combined by age group using Bayesian hierarchical modeling. The effects of exposure to particulate matter <10 micrometers in aerodynamic diameter (PM₁₀), carbon monoxide (CO) and nitrogen dioxide (NO₂) varied significantly by age groups. Using adults as the referent, the relative rate (RR) of asthma admissions with 10µg/m³ increase of PM₁₀ is 1.5% (95%CI: 0.1–2.8%) lower for children, and 1.3% (95% CI: 0.7–1.9%) higher for the elderly; RR with 1ppm increase of CO is 1.9% (95% CI: 0.3–3.8%) lower for children; RR with 1ppb increase of NO₂(1ppb) is 0.5% (95% CI: 0.3–0.7%) higher for the elderly. No significant age group difference in relative rate was found for ozone or sulfur dioxide.

Introduction

Numerous studies reported relationships between air pollution and mortality or morbidity over many decades. Particularly, asthma is the one that air pollution is regarded as a possible contributor to its prevalence (Baibergenova et al., 2005; Berktaş & Bircan, 2003; Dab et al., 1996; Galan, Tobias, Banegas, & Aranguez, 2003; Halonen et al., 2008; Ho et al., 2007). Air Pollution and Health European Approach (APHEA) conducted pivotal studies about effects of air pollution on health in ten European countries, finding evidence of adverse air pollution effects on respiratory diseases including asthma in urban areas using an epidemiologic time series approach (Katsouyanni et al., 1995; Katsouyanni et al., 1997; Vigotti, 1999). One of the largest studies in the United States, The National Morbidity, Mortality, and Air Pollution Study (NMMAPS) reported morbidity of asthma associated with air pollution (Samet et al., 2000). Also in Korea, several studies on acute asthma caused by air pollution have been conducted in order to address the high mortality rate (Ho et al., 2007; D. H. Kim et al., 2007; S. Y. Kim, Kim, & Kim, 2006; S. Y. Kim et al., 2007), since mortality from respiratory diseases, including asthma, increased hundred percent in the decade from 1992 to 2002 (Cho, Park, & Rosenberg, 2006).

Asthma is separately diagnosed by age, usually two groups, age <15 yr as child-onset and age >15 as adult-onset asthma. Hence, asthma researches associated with air pollution have been investigated separately by age group, mostly focused on childhood asthma (Dockery et al., 1989; Gergen, Mullally, & Evans, 1988; J. H. Kim et al., 2005; Lee et al., 2002; Lee, Son, Kim, & Kim, 2006; Lin et al., 2002; Mortimer et al., 2002; Norris et al., 1999; Schildcrout et al., 2006; Son et al., 2006). However, no study has been conducted in Korea to assess differences of the air pollutant effect on asthma prevalence by age group and

whether these are significant differences. Therefore, it is necessary to evaluate whether air pollution effects associated with acute asthma prevalence differ according to age classification.

We tested null hypothesis that air pollution effects are statistically different on three age groups: (1) ages less than 15 yrs. (childhood asthma), (2) ages 15–64 yrs. and (3) ages over 65 (elderly) with two stage model. In the first stage, we used time-series analysis based on Poisson regression to estimate age-specific effects for each city (Dominici et al., 2002; Peng et al., 2006; Schwartz et al., 1996). And Bayesian Hierarchical modeling was used in the second state to combine the estimates across seven cities by age group in Korea (Dominici et al. 2000).

Materials and methods

Hospital administration data

The Korean National Health Insurance Corporation registered asthma-related hospital admissions data between June 1, 1999 and December 31, 2003. The data have emergency room visits including night time or holiday visits prompted by asthma (classified as 'J45', 'J46' by ICD-10). Two or more visits by the same person in the same day were counted as one episode. Daily counts for asthma were aggregated in each of the seven metropolitan cities (Figure 1) for the three age groups between June 1999 and December 2003.

Meteorological data

Hourly data on temperature (°C), humidity (%), sea-level atmospheric pressure (hPa), and wind speed (m/s), and 3-hour dew point temperature (°C) data were obtained from the Korea Meteorological Offices in the seven cities. Three-hour Atmospheric Pasquill Stability classifications were obtained from the U.S. National Oceanic and Atmospheric Administration (NOAA). Atmospheric stability was designated on a scale of A (extremely unstable) to G (extremely stable), and data on this variable were also obtained from each city's observatory. This variable was dichotomized by substituting a value of zero for A-C status levels, and 1 for D-G status levels (Kwon et al., 2006).

Environmental monitoring data

Hourly air pollutant monitoring data were collected at each of the following monitoring stations (the following numbers in parentheses represents the number of monitoring stations in each city): Seoul (27), Busan (9), Incheon (10), Daegu (6), Gwangju (4), Daejeon (3), and Ulsan (11). Reported air quality concentration data were collected for PM₁₀ (µg/m³), CO (ppm), O₃ (ppb), NO₂ (ppb), and SO₂ (ppb). Five percent trimmed daily averages were taken from hourly measured air pollutant concentrations for each monitoring station (i.e. an average after trimming 5% of the data points from top and bottom of the distributions). An average of concentrations was then calculated for each city using the daily averaged concentrations from each monitoring station within the city.

First stage analysis

Data were analyzed in two stages. The first stage was involved in estimating air pollution effect by age group for each city by using a log-linear generalized additive model (GAM) based on Poisson regression with smoothing splines. This method is commonly used in time-series studies related to mortality or hospital counts (Schwartz, 1994) such as NMMAPS data (Dominici 2002). The “mgcv” package was used for estimating parameters in the first stage by generalized cross validation (GCV) or unbiased risk estimation (UBRE) (Wood, 2009), which is different from others in model fitting and variance estimation. In this paper, long-term seasonality, day of week effect, meteorological data were considered

as potential confounders. The day of week effect was included due to the properties of hospital admission data. In the previous studies, temperature, dew point temperature, average temperature and average dew point temperature for the three previous days had been considered as major confounders of evaluating air pollution effect on asthma admissions (Dominici et al. 2000; Samet et al., 2000). Hence, these six variables were always included as confounders in models, setting as a baseline model. In addition to the baseline model, other meteorological variables which are humidity, sea-level atmospheric pressure, wind speed and Atmospheric Pasquill Stability were also added only if each factor showed significant contribution to the model by backwards variable selection with five percent significance level (Wood, 2009).

$$Y_{at}^c | \mu_{at}^c \sim \text{Poisson}(\mu_{at}^c), t=1, \dots, 1675, c=1, \dots, 7, a=1, 2, 3$$

$$\begin{aligned} \text{Log}(\mu_{at}^c) = & \beta^{c*}(\text{Air pollutant})_t^c + \beta_{\text{age}<15}^{c*}(\text{Air pollutant})_t^c I_{\text{age}<15} + \beta_{\text{age}\geq 65}^{c*}(\text{Air pollutant})_t^c I_{\text{age}\geq 65} \\ & + \gamma^{c*} \text{DOW}_t(\text{day of week}) + S_1^c(\text{time}, 8/\text{year}) \\ & + S_2^c(\text{temp}_0, 3) + S_3^c(\text{temp}_{1-3}, 3) \\ & + S_4^c(\text{dewpoint}_0, 4) + S_5^c(\text{dewpoint}_{1-3}, 4) \\ & + S_1^c(\text{others}, \lambda_i) \\ & + \text{intercept for age group } a (\beta_0^c, \beta_{0,\text{age}<15}^{c*} I_{\text{age}<15}, \beta_{0,\text{age}\geq 65}^{c*} I_{\text{age}\geq 65}) \\ & + \text{separate smoothing functions of time for age group} \end{aligned}$$

,where separate smoothing functions of time for age group is the age-specific seasonality smoothing function with 4 degrees of freedom per year. The $S^c(x, \cdot)$ is smoothing function with variable x and smoothing parameter $\cdot$. The natural splines model was applied for smoothing functions in this paper. The smoothing parameter for long-term seasonality was eight per year in terms of best fit in the data after checking through sixteen parameters per year for seasonality. A smoothing parameter for other meteorological confounders except the baselines was selected by minimizing GVC. In addition to daily mean on the same day as asthma admissions, the average mean from previous three days for each meteorological variable were also considered. For air pollution, the largest log-RRs were selected from the last six days after rates were estimated for each day separately. To specify this approach, let Y_{at}^c and μ_{at}^c be daily sum and expected sum per 10,000 of asthma admissions for each age group a ($1=(\text{age}<15)$; $2=(15 \leq \text{age}<65)$; $3=(\text{age} \geq 65)$). $(\text{Air pollutant})_t^c$ is the concentration level of one of the air pollutants at day t in city c . The indicator function 'I' is defined as follows: $I_A(x)=1$ if $x \in A$, $I_A(x)=0$ if $x \notin A$. For example, $I_{\text{age}<15}=1$, if the subject is in age < 15 and 0, otherwise. The Y_{at}^c is daily sum per 10,000 of asthmatic hospital admissions adjusted by population size for each city. Hence, the estimate β^{c*} is the log RR per 10,000 of asthma admissions associated with one unit change of air pollutant in the city c for adults in age between 15 and 64 (reference group; no subscript for age group). Additional changes of log-RRs for each of children and the elderly from log-RR for adults are $\beta_{\text{age}<15}^{c*}$ and $\beta_{\text{age} \geq 65}^{c*}$ in city c , respectively. If at least one of these additional changes are not equal to zero, we conclude that air pollution effect on asthma admission differs by age group. Each β s were estimated separately by city and age group.

Second stage analysis

The null hypothesis in the second stage is $H_0: \beta_{\text{age}<15}^{c*} = \beta_{\text{age} \geq 65}^{c*} = 0$. The estimates of additional changes of log-relative rates from two age groups, age < 15 and age ≥ 65 , $\widehat{\beta_{\alpha}^c}$ were assumed to be normally distributed with the true additional changes for two age groups (age < 15 , age ≥ 65) from adults (age 15–64) for each city, β^{c*} and its variances $\sigma_{\beta_{\alpha}^c}^2$. These

estimated changes for each city were combined assuming normal for prior distribution with mean β_{α} and variance $\sigma_{\beta_{\alpha}}^2$. We assumed no prior information for variance $\sigma_{\beta_{\alpha}}^2$. This was applied to all five air pollutants in this paper. For this study, *WinBUGS*, software for Bayesian analysis using Markov Chain Monte Carlo, was used to estimate combined additional changes of log-relative rates for two age groups (age<15, age ≥ 65) comparing to log relative rate for adults (age 15–64), with very large variance implicating no prior information given for posterior estimation.

$$\widehat{\beta_{\alpha^c}} | \beta_{\alpha^c} \sim N(\beta_{\alpha^c}, \sigma_{\beta_{\alpha^c}}^2)$$

$$\beta_{\alpha^c} | \beta_{\alpha} \sim N(\beta_{\alpha}, \sigma_{\beta_{\alpha}}^2), c=1, \dots, 7, \quad a=1, 3$$

Results

Table 1 shows population size, hospital admission numbers for asthma and asthma admission rates (per 10,000: adjusted by population size) for each city by age group. Admission rates for adults were much less than for the other age groups, and the elderly tended to have the highest rates among the three. Time-series plots for daily asthma admission rates are presented for each city by age group in Figure 2. The dots are actual asthma admission rates and the curves in the plot were fitted by generalized linear model using natural splines function with 8/year as smoothing parameter. The same format was also applied to Figure 3. The graphs showed three peaks of admission rates in 1999, 2000, and in 2002. Usually asthma admission rates tended to increase in the fall and winter. However, the peak time and pattern are not identical in age groups. In children, the first peak occurred around November 1999, whereas it occurred between the end of December 1999 and January 2000 for adults and elderly people. The adults and elderly groups did not have a second peak. The third peak occurred at the same time period in all age groups. Children's admission rates showed a lot more variability than other age groups.

Statistical summaries of each of the five air pollutant concentrations for each city are shown in Table 2. The capital of South Korea, Seoul, had the highest average concentrations of PM₁₀ and NO₂, but the lowest levels of ozone. Figure 3 shows the time series plot for daily averages of air pollution concentrations for each city. PM₁₀ tended to increase in spring for all seven cities. Daejeon showed a much higher level of CO than any other city between 1999 and 2001. CO showed a huge drop in Gwangju around February 2003. CO also had a pattern of increasing in winter and decreasing in summer. O₃ had a reverse pattern which had two peaks per year, one was around June and another one was in September from 2001 to 2003. NO₂ and SO₂ did not show any particular seasonality, but tended to be higher during the winter and show a minimum around September. Table 3 shows estimated changes of log relative rates, its standard errors, relative rates and its 95% confidence intervals on asthmatic hospital admission rates (per 10,000) across seven cities in South Korea associated with one unit change of air pollution for each age group. Relative rates (RRs) of asthma admission rates (per 10,000) with 10µg/m³ increase of PM₁₀ significantly increased 0.8% (95% CI: 0.2–0.16%) for adults (15–64 yr) and 2.1% (95% CI: 1.3–2.9%) for the elderly (≥ 65 yr). RRs with 1ppm increase of CO also significantly increased 1.9% (95%CI: 0.5–3.3%) for adults and 2.2% (95%CI: 1.2–3.3%) for the elderly. And RRs with 1 ppb increase of NO₂ and SO₂ increased 0.6% (95%CI: 0.2–0.9%) and 1.9% (95%CI: 0.7–3.2%) for the elderly. Table 4 shows estimated additional changes of log-relative rates, its standard errors, relative rates and its 95% confidence intervals on asthmatic hospital admission rates (per 10,000) across all seven cities associated with one unit change of air pollution regarding adults (15–64 yr) as a reference group. The estimates in Table 4 are additional changes of log RRs of each pollutant for children (<15yr) and the elderly (≥ 65 yr), referring to log RRs

for adults (age 15–64). RRs with $10\mu\text{m}^3$ increase of PM_{10} significantly differ by age group; RR for children is 0.15% lower and RR for the elderly is 0.13% higher than RR for adults. It shows significantly lower RR (1.9%) with CO for children and higher RR (0.5%) with NO_2 for the elderly comparing to RR for adults. Based on the hypothesis test, we concluded air pollution effects for three air pollutants (PM_{10} , CO, NO_2) on asthma hospitalization rates are significantly different in at least two of three groups. There appeared to be no significant difference among age groups for O_3 and SO_2 .

Discussion

The study was to investigate whether air pollution effects on acute asthma differ by age classification. In Table 3, estimated changes of log-relative rates and confidence intervals across seven cities have been shown for three age groups, and none of pollutants has shown a protective effect. Nonetheless, Table 4 shows significantly negative effects in PM_{10} and CO for children since these are additional changes compared to the effects for adults which mean that childhood asthma was less sensitively affected by these two pollutants than adult-onset asthma. In the same manner, positive additional changes of log-relative rates in PM_{10} and NO_2 for elderly persons mean that the elderly was at significantly higher risk than adults on these two pollutants. Based on the results, we concluded that the effects of PM_{10} , CO and NO_2 significantly differ by age group, and the elderly was the most vulnerable group to the effect of PM_{10} and NO_2 . In light of previous research which reported a significant association between air pollutants and childhood asthma hospitalizations in Seoul, Korea (Lee et al., 2002), the elderly might be at even higher risk, although it is not comparable in direct since it had different study periods. Based on the results of this study, elderly persons were affected by PM_{10} , NO_2 significantly more than children or adults. On the other hand, other study found no age difference of associations between air pollution and asthma or pulmonary diseases as follows. In APHEA 2 report 2001 (Atkinson et al., 2001), investigators estimated $\text{PM}_{10}/\text{TSP}$ effects on asthmatic hospital admission for eight cities separately for each age group (0–14 yr, 15–64 yr, 65+ yr). They combined city-specific effects by age group counting on heterogeneity across the cities. And these combined estimates for each age group were close to each other, did not show the difference among age groups in $\text{PM}_{10}/\text{TSP}$. This is different conclusion from our finding in this paper. There can be many reasons for this discrepancy; two possibilities are specified as follows. One is the different measurement on particles. Of eight cities, two cities (Milan, Rome) recorded median daily TSP levels and one city (Paris) measured PM_{13} . In contrast, we measured PM_{10} for all seven cities. Even though the correlations among PM_{10} , PM_{13} , and TSP are relatively high, this may contribute some of discrepancy since the results were combined across cities. Another possibility is different population for the elderly. APHEA 2 report in 2001 included population in hospital admissions for COPD in addition to asthma, yet we included only asthma admissions due to limited access to information. Since it is difficult to distinguish between COPD and asthma in elderly population due to other factors such as smoking (Bellia et al., 2003; Tinkelman et al., 2006), different population setting may provoke substantial differences in conclusion. This may be an important limitation of this study. Nonetheless, the use of hospital admission and discharge data have been found to be more reliable and less prone to misclassification when differentiating COPD and asthma in elderly persons as compared to self-reported data since the asthma data used is hospital admission discharge data (Radeos et al., 2009). We also recognize that exploring better ways to avoid this misclassification are needed. However, for children (<15 yr), the results in Table 3 showed consistency with previous researches that there is no significant increase of relative rates on childhood asthma admissions associated with air pollutant levels (Anderson et al., 2010; Anderson et al., 2012).

For hypothesis testing, we combined seven estimates from each city by using a Bayesian approach assuming homogeneity across seven cities since these seven cities are designated as metropolitan areas in Korea based on criteria such as population size. However, possible heterogeneity, caused by different locations or contributors of the air pollution effects on asthma hospital admissions, may be an important limitation of the study. For example, socioeconomic status (Lee et al., 2006), one of the important factors in childhood asthma, could be different in the populations of these cities. Polluting sources could be also different among seven cities, for example, the largest auto making industry in Ulsan.

We considered only meteorological factors, which have been shown to be associated with respiratory diseases (Abe et al. 2009; Dominici et al. 2006; Gosai et al. 2009; Wong et al. 1987), as confounders in this paper. However, other than meteorological factors, childhood asthma may be more influenced by some other factors such as genetic predisposition which needs to be considered in further research. Multiple pollutant models also can be considered in further studies since some air pollutants are related each other. Bias may be addressed in this study due to the characteristics of hospital admission data which counted only emergency room visit patients who may not represent all asthmatic patients. We suggest further study considering possible limitations we address here in addition to our major suggestion based on the study results which is to be aware of different air pollution effects by age classification and to pay more attention to asthma in elderly differing from childhood asthma.

References

- Abe T, Tokuda Y, Ohde S, Ishimatsu S, Nakamura T, Birrer RB. The relationship of short-term air pollution and weather to ED visits for asthma in Japan. *The American Journal of Emergency Medicine*. 2009; 27(2):153–159. [PubMed: 19371521]
- Anderson HR, Butland BK, van Donkelaar A, Brauer M, Strachan DP, Clayton T, et al. Satellite-based estimates of ambient air pollution and global variations in childhood asthma prevalence. *Environmental Health Perspectives*. 2012; 120(9):1333–1339. [PubMed: 22548921]
- Anderson HR, Ruggles R, Pandey KD, Kapetanakis V, Brunekreef B, Lai CK, et al. Ambient particulate pollution and the world-wide prevalence of asthma, rhinoconjunctivitis and eczema in children: Phase one of the international study of asthma and allergies in childhood (ISAAC). *Occupational and Environmental Medicine*. 2010; 67(5):293–300. [PubMed: 19819866]
- Atkinson RW, Anderson HR, Sunyer J, Ayres J, Baccini M, Vonk JM, et al. Acute effects of particulate air pollution on respiratory admissions: Results from APHEA 2 project. *Air pollution and health: A European approach*. *American Journal of Respiratory and Critical Care Medicine*. 2001; 164(10 Pt 1):1860–1866. [PubMed: 11734437]
- Baibergenova A, Thabane L, Akhtar-Danesh N, Levine M, Gafni A, Moineddin R, et al. Effect of gender, age, and severity of asthma attack on patterns of emergency department visits due to asthma by month and day of the week. *European Journal of Epidemiology*. 2005; 20(11):947–956. [PubMed: 16284873]
- Bellia V, Battaglia S, Catalano F, Scichilone N, Incalzi RA, Imperiale C, et al. Aging and disability affect misdiagnosis of COPD in elderly asthmatics: The SARA study. *Chest*. 2003; 123(4):1066–1072. [PubMed: 12684295]
- Berktaş BM, Bircan A. Effects of atmospheric sulphur dioxide and particulate matter concentrations on emergency room admissions due to asthma in Ankara. *Tuberkuloz Ve Toraks*. 2003; 51(3):231–238. [PubMed: 15143399]
- Cho SH, Park HW, Rosenberg DM. The current status of asthma in Korea. *Journal of Korean Medical Science*. 2006; 21(2):181–187. [PubMed: 16614498]
- Dab W, Medina S, Quenel P, Le Moulec Y, Le Tertre A, Thelot B, et al. Short term respiratory health effects of ambient air pollution: Results of the APHEA project in Paris. *Journal of Epidemiology and Community Health*. 1996; 50(Suppl 1):s42–6. [PubMed: 8758223]

- Dockery DW, Speizer FE, Stram DO, Ware JH, Spengler JD, Ferris BG Jr. Effects of inhalable particles on respiratory health of children. *The American Review of Respiratory Disease*. 1989; 139(3):587–594. [PubMed: 2923355]
- Dominici F, McDermott A, Zeger SL, Samet JM. On the use of generalized additive models in time-series studies of air pollution and health. *American Journal of Epidemiology*. 2002; 156(3):193–203. [PubMed: 12142253]
- Dominici F, Peng RD, Bell ML, Pham L, McDermott A, Zeger SL, et al. Fine particulate air pollution and hospital admission for cardiovascular and respiratory diseases. *JAMA : The Journal of the American Medical Association*. 2006; 295(10):1127–1134. [PubMed: 16522832]
- Dominici F, Samet JM, Zeger SL. Combining evidence on air pollution and daily mortality from the 20 largest US cities: A hierarchical modelling strategy. *Journal of the Royal Statistical Society*. 2000; (163):263–302.
- Galan I, Tobias A, Banegas JR, Aranguiz E. Short-term effects of air pollution on daily asthma emergency room admissions. *The European Respiratory Journal : Official Journal of the European Society for Clinical Respiratory Physiology*. 2003; 22(5):802–808.
- Gergen PJ, Mullally DI, Evans R 3rd. National survey of prevalence of asthma among children in the united states, 1976 to 1980. *Pediatrics*. 1988; 81(1):1–7. [PubMed: 3336575]
- Gosai A, Salinger J, Dirks K. Climate and respiratory disease in auckland, new zealand. *Australian and New Zealand Journal of Public Health*. 2009; 33(6):521–526. [PubMed: 20078568]
- Halonen JI, Lanki T, Yli-Tuomi T, Kulmala M, Tiittanen P, Pekkanen J. Urban air pollution, and asthma and COPD hospital emergency room visits. *Thorax*. 2008; 63(7):635–641. [PubMed: 18267984]
- Ho WC, Hartley WR, Myers L, Lin MH, Lin YS, Lien CH, et al. Air pollution, weather, and associated risk factors related to asthma prevalence and attack rate. *Environmental Research*. 2007; 104(3):402–409. [PubMed: 17316602]
- Katsouyanni K, Touloumi G, Spix C, Schwartz J, Balducci F, Medina S, et al. Short-term effects of ambient sulphur dioxide and particulate matter on mortality in 12 european cities: Results from time series data from the APHEA project. *air pollution and health: A european approach*. *BMJ (Clinical Research Ed.)*. 1997; 314(7095):1658–1663.
- Katsouyanni K, Zmirou D, Spix C, Sunyer J, Schouten JP, Ponka A, et al. Short-term effects of air pollution on health: A european approach using epidemiological time-series data. *the APHEA project: Background, objectives, design*. *The European Respiratory Journal : Official Journal of the European Society for Clinical Respiratory Physiology*. 1995; 8(6):1030–1038.
- Kim DH, Kim YS, Park JS, Kwon HJ, Lee KY, Lee SR, et al. The effects of on-site measured ozone concentration on pulmonary function and symptoms of asthmatics. *Journal of Korean Medical Science*. 2007; 22(1):30–36. [PubMed: 17297248]
- Kim JH, Kim JK, Son BK, Oh JE, Lim DH, Lee KH, et al. Effects of air pollutants on childhood asthma. *Yonsei Medical Journal*. 2005; 46(2):239–244. [PubMed: 15861497]
- Kim SY, Kim H, Kim J. Effects of air pollution on asthma in seoul: Comparisons across subject characteristics. *Journal of Preventive Medicine and Public Health = Yebang Uihakhoe Chi*. 2006; 39(4):309–316. [PubMed: 16910304]
- Kim SY, O'Neill MS, Lee JT, Cho Y, Kim J, Kim H. Air pollution, socioeconomic position, and emergency hospital visits for asthma in seoul, korea. *International Archives of Occupational and Environmental Health*. 2007; 80(8):701–710. [PubMed: 17357797]
- Kwon J, Weisel CP, Turpin BJ, Zhang J, Korn LR, Morandi MT, et al. Source proximity and outdoor-residential VOC concentrations: Results from the RIOPA study. *Environmental Science & Technology*. 2006; 40(13):4074–4082. [PubMed: 16856719]
- Lee JT, Kim H, Schwartz J. Bidirectional case-crossover studies of air pollution: Bias from skewed and incomplete waves. *Environmental Health Perspectives*. 2000; 108(12):1107–1111. [PubMed: 11133389]
- Lee JT, Kim H, Song H, Hong YC, Cho YS, Shin SY, et al. Air pollution and asthma among children in seoul, korea. *Epidemiology (Cambridge, Mass.)*. 2002; 13(4):481–484.

- Lee JT, Son JY, Kim H, Kim SY. Effect of air pollution on asthma-related hospital admissions for children by socioeconomic status associated with area of residence. *Archives of Environmental & Occupational Health*. 2006; 61(3):123–130. [PubMed: 17672354]
- Lin M, Chen Y, Burnett RT, Villeneuve PJ, Krewski D. The influence of ambient coarse particulate matter on asthma hospitalization in children: Case-crossover and time-series analyses. *Environmental Health Perspectives*. 2002; 110(6):575–581. [PubMed: 12055048]
- Mortimer KM, Neas LM, Dockery DW, Redline S, Tager IB. The effect of air pollution on inner-city children with asthma. *The European Respiratory Journal : Official Journal of the European Society for Clinical Respiratory Physiology*. 2002; 19(4):699–705.
- Norris G, YoungPong SN, Koenig JQ, Larson TV, Sheppard L, Stout JW. An association between fine particles and asthma emergency department visits for children in seattle. *Environmental Health Perspectives*. 1999; 107(6):489–493. [PubMed: 10339450]
- Peng RD, Dominici F, Louis TA. Model choice in time series studies of air pollution and mortality. *Journal of the Royal Statistical Society: Series A*. 2006; 169(Part 2):179–203.
- Radeos MS, Cydulka RK, Rowe BH, Barr RG, Clark S, Camargo CA Jr. Validation of self-reported chronic obstructive pulmonary disease among patients in the ED. *The American Journal of Emergency Medicine*. 2009; 27(2):191–196. [PubMed: 19371527]
- Samet JM, Zeger SL, Dominici F, Curriero F, Coursac I, Dockery DW, et al. The national morbidity, mortality, and air pollution study. part II: Morbidity and mortality from air pollution in the united states. *Research Report (Health Effects Institute)*. 2000; 94(Pt 2):5–70. discussion 71–9.
- Schildcrout JS, Sheppard L, Lumley T, Slaughter JC, Koenig JQ, Shapiro GG. Ambient air pollution and asthma exacerbations in children: An eight-city analysis. *American Journal of Epidemiology*. 2006; 164(6):505–517. [PubMed: 16798793]
- Schwartz J. Nonparametric smoothing in the analysis of air pollution and respiratory illness. *Canadian Journal of Statistics*. 1994; 22(4):471–487.
- Schwartz J, Spix C, Touloumi G, Bacharova L, Barumamdzadeh T, le Tertre A, et al. Methodological issues in studies of air pollution and daily counts of deaths or hospital admissions. *Journal of Epidemiology and Community Health*. 1996; 50(Suppl 1):S3–11. [PubMed: 8758217]
- Son JY, Cho YS, Lee JT. Effects of air pollution on postneonatal infant mortality among firstborn infants in seoul, korea: Case-crossover and time-series analyses. *Archives of Environmental & Occupational Health*. 2008; 63(3):108–113. [PubMed: 18980873]
- Son JY, Kim H, Lee JT, Kim SY. Relationship between the exposure to ozone in seoul and the childhood asthma-related hospital admissions according to the socioeconomic status. *Journal of Preventive Medicine and Public Health = Yebang Uihakhoe Chi*. 2006; 39(1):81–86. [PubMed: 16613076]
- Tinkelman DG, Price DB, Nordyke RJ, Halbert RJ. Misdiagnosis of COPD and asthma in primary care patients 40 years of age and over. *The Journal of Asthma : Official Journal of the Association for the Care of Asthma*. 2006; 43(1):75–80. [PubMed: 16448970]
- Vigotti MA. Short-term effects of exposure to urban air pollution on human health in europe. the APHEA projects (air pollution and health: A european approach. [Effetti a breve termine prodotti dalla esposizione ad inquinamento atmosferico urbano sulla salute umana in Europa. I Progetti APHEA (Air Pollution and Health: a European Approach)]. *Epidemiologia e Prevenzione*. 1999; 23(4):408–415. [PubMed: 10730486]
- Wong KW, Davies DP, Lau EM. Asthma and climatic conditions: Experiences from hong kong. *British Medical Journal (Clinical Research Ed.)*. 1987; 294(6564):119. [PubMed: 3105641]
- Wood, S. Mgcov: GAMs with GCV/AIC/REML smoothness estimation and GAMMs by PQL. 2009.

Fig. 1.
Map of seven metropolitan cities in South Korea

Fig. 2.
Time-series plot for daily number of hospital admissions for asthma in each city by age group (<15, 15–64, ≥65), from June 1999 to December 2003

Fig. 3.
Time-series plot for 10% daily trimmed means of air pollutant concentrations for each city, from June 1999 to December 2003

Table 1

Population size, hospital admissions and rates (per 10,000) for asthma in each city by age group from June 1999 to December 2003

City	Age group	Population size	Admissions	Admissions per 10,000
Seoul				
	<15	1,814,097	44,432	245
	15–64	7,284,748	22,547	31
	65	533,053	19,136	359
Busan				
	<15	682,292	25,630	376
	15–64	2,655,396	10,133	38
	65	223,275	10,799	484
Incheon				
	<15	572,823	12,024	210
	15–64	1,713,564	5,460	32
	65	135,455	5,247	387
Daegu				
	<15	512,759	17,092	333
	15–64	1,758,418	5,532	31
	65	146,140	5,509	377
Gwangju				
	<15	308,722	14,296	463
	15–64	930,174	4,385	47
	65	74,714	3,980	533
Daejeon				
	<15	302,798	6,766	223
	15–64	945,561	3,593	38
	65	74,089	3,576	483
Ulsan				
	<15	252,810	5,257	208
	15–64	692,876	2,119	31
	65	40,729	2,530	621

Table 2

Distribution of daily average * air pollution concentrations for each city from June 1999 to December 2003

	Mean	Standard Deviation	Median	25 percentile	75 percentile	Range[Min,Max]
PM ₁₀ (µg /m ³)						
Korean Ambient Air Quality Standard for 24-hour averaging time; 100 µg/m ³						
Seoul	68.81	38.94	62.88	42.46	84.24	[10.39,422.72]
Busan	59.85	27.86	52.95	41.31	70.72	[22.15,321.06]
Incheon	53.45	29.48	47.00	33.04	65.92	[11.51,270.38]
Daegu	61.66	27.34	56.21	43.02	74.51	[9.63,287.62]
Gwangju	50.17	26.17	43.81	33.66	59.58	[10.60,237.18]
Daejeon	48.06	25.12	42.27	30.96	58.40	[10.09,265.57]
Ulsan	49.09	23.89	43.08	34.02	58.43	[16.26,286.20]
CO (ppm)						
Korean Ambient Air Quality Standard for 24-hour averaging time; 9 ppm						
Seoul	0.783	0.343	0.700	0.536	0.934	[0.253,4.847]
Busan	0.728	0.257	0.679	0.545	0.848	[0.178,1.823]
Incheon	0.682	0.247	0.625	0.517	0.776	[0.303,2.309]
Daegu	0.755	0.324	0.685	0.539	0.898	[0.131,2.554]
Gwangju	0.624	0.302	0.570	0.424	0.760	[0.100,2.107]
Daejeon	0.969	0.511	0.829	0.617	1.179	[0.113,4.570]
Ulsan	0.665	0.227	0.630	0.500	0.786	[0.225,1.583]
O ₃ (ppb) [†]						
Korean Ambient Air Quality Standard for 8-hour averaging time; 0.06ppm						
Seoul	0.021	0.013	0.013	0.008	0.019	[0.002,0.048]
Busan	0.029	0.011	0.023	0.017	0.028	[0.004,0.058]
Incheon	0.024	0.012	0.017	0.012	0.024	[0.002,0.050]
Daegu	0.026	0.013	0.018	0.012	0.024	[0.003,0.060]
Gwangju	0.022	0.011	0.016	0.010	0.022	[0.000,0.066]
Daejeon	0.026	0.013	0.017	0.011	0.025	[0.002,0.071]
Ulsan	0.028	0.010	0.021	0.016	0.027	[0.004,0.052]
NO ₂ (ppb)						
Korean Ambient Air Quality Standard for 24-hour averaging time; 0.06ppm						
Seoul	0.036	0.012	0.035	0.027	0.045	[0.011,0.075]
Busan	0.026	0.009	0.024	0.019	0.032	[0.006,0.059]
Incheon	0.027	0.010	0.026	0.019	0.033	[0.007,0.071]
Daegu	0.027	0.010	0.025	0.020	0.033	[0.007,0.068]
Gwangju	0.022	0.009	0.021	0.015	0.027	[0.005,0.059]
Daejeon	0.022	0.011	0.019	0.014	0.027	[0.004,0.069]
Ulsan	0.020	0.007	0.020	0.015	0.024	[0.005,0.047]
SO ₂ (ppb)						
Korean Ambient Air Quality Standard for 24-hour averaging time; 0.05ppm						
Seoul	0.005	0.002	0.005	0.003	0.006	[0.002,0.016]

	Mean	Standard Deviation	Median	25 percentile	75 percentile	Range[Min,Max]
Busan	0.008	0.004	0.008	0.005	0.010	[0.001,0.030]
Incheon	0.007	0.002	0.006	0.005	0.008	[0.002,0.017]
Daegu	0.007	0.004	0.006	0.004	0.009	[0.002,0.024]
Gwangju	0.005	0.002	0.004	0.003	0.006	[0.001,0.016]
Daejeon	0.006	0.003	0.005	0.003	0.007	[0.002,0.020]
Ulsan	0.008	0.003	0.007	0.006	0.009	[0.003,0.021]

*
For ozone, average for 09–17 hr

Table 3

Estimated changes of log-relative rates, its standard errors, relative rates and its 95% confidence intervals on asthmatic hospital admission rates (per 10,000) across seven cities in South Korea associated with one unit[§] change of air pollution for each age group, from June 1999 to December 2003.

Air pollutant	Age group (years)	Estimate	Standard Error	RR (95% CI)
PM ₁₀ ($\mu\text{g}/\text{m}^3$)				
	<15	-0.007	0.006	0.9930(0.9814,1.0048)
	15-64	0.008	0.004	1.0080(1.0002,1.0160)*
	65	0.021	0.004	1.0212(1.0132,1.0293)*
CO (ppm)				
	<15	-0.0007	0.0048	0.9993(0.99,1.0087)
	15-64	0.0187	0.007	1.0189(1.0049,1.033)*
	65	0.0219	0.0053	1.0221(1.0115,1.0329)*
O ₃ (ppb) [†]				
	<15	-0.0011	0.0016	0.9989(0.9957,1.0021)
	15-64	-0.0004	0.0007	0.9996(0.9981,1.001)
	65	-0.0001	0.0013	0.9999(0.9974,1.0023)
NO ₂ (ppb)				
	<15	0.0015	0.0016	1.0015(0.9984,1.0046)
	15-64	0.0006	0.001	1.0006(0.9986,1.0026)
	65	0.0056	0.0019	1.0056(1.0019,1.0093)*
SO ₂ (ppb)				
	<15	-0.0125	0.0095	0.9876(0.9694,1.0061)
	15-64	0.0083	0.0052	1.0084(0.9981,1.0188)
	65	0.019	0.0062	1.0192(1.007,1.0316)*

* Statistically significant

[†] For ozone, average for 09-17 hr

[§] PM₁₀=10 $\mu\text{g}/\text{m}^3$, CO=1ppm, O₃=1ppb, NO₂=1ppb, SO₂=1ppb

Table 4

Estimated additional changes of log-relative rates, its standard errors, relative rates and its 95% confidence intervals on asthmatic hospital admissions (per 10,000) across seven cities in South Korea associated with one unit[§] change of air pollution compared to adults (15–64 yr) as a reference group, from June 1999 to December 2003.

Air pollutant	Age group (years)	Estimate	Standard Error	RR (95% CI)
PM ₁₀ (μg /m ³)	<15	−0.015	0.007	0.9851(0.9717,0.9987) *
	65	0.013	0.003	1.0131(1.0071,1.0191) *
CO (ppm)	<15	−0.0195	0.0098	0.9807(0.9621,0.9997) *
	65	0.0031	0.0032	1.0031(0.9969,1.0094)
O ₃ (ppb) [†]	<15	−0.0007	0.0016	0.9993(0.9962,1.0024)
	65	0.0003	0.0009	1.0003(0.9985,1.0021)
NO ₂ (ppb)	<15	0.0009	0.0017	1.0009(0.9976,1.0042)
	65	0.0049	0.0011	1.0049(1.0028,1.0071) *
SO ₂ (ppb)	<15	−0.0208	0.0113	0.9794(0.9581,1.0013)
	65	0.0106	0.0056	1.0107(0.9997,1.0218)

* Statistically significant

[†] For ozone, average for 09–17 hr

[§] PM₁₀=10μg/m³, CO=1ppm, O₃=1ppb, NO₂=1ppb, SO₂=1ppb