

Effect of Weed Pollen on Children's Hospital Admissions for Asthma During the Fall Season

Wansoo Im, PhD; Dona Schneider, PhD

ABSTRACT. The authors analyzed temporal variations in asthma hospital admissions for New Jersey children (0–14 years of age) over a 3-year period. Significant spikes in children's asthma hospital admissions occurred during late September and early October of each of the 3 years of the study. The authors report on an in-depth analysis of the fall peak periods, in an effort to determine whether there was an association between children's asthma hospital admissions and environmental variables. Hospital admission peaks occurred approximately 3 weeks after school started and before heating systems were turned on in New Jersey public schools. They also preceded the point at which schools begin to report increased absences that are due to infectious illnesses. An examination of environmental variables showed only weed pollen as a statistically significant predictor of children's asthma hospital admissions during the fall peaks ($p < .001$). The counseling of parents about children's exposure to pollen and possible ways to reduce such exposure should be part of the asthma management protocols for children living in high-pollen environments.

KEY WORDS: air pollution, asthma, children, ozone, pollen

Seasonal variations in asthma have been widely documented.^{1–5} Fleming et al⁴ found that, in England, there was a peak in asthma hospital admissions during late September for children in the age groups of 0–4 and 5–14 years. Crighton et al³ found a similar trend for Ontario, Canada, during the fall season for each year from 1988 to 2000. Researchers have examined most seasonal variations in asthma for linkages to environmental variables, especially air pollutants and household mites.^{6–10} Experimental and epidemiological studies also show that air pollution aggravates asthma problems.^{9,11} In New Jersey (NJ), we found that a large portion of children's annual hospital admissions for asthma occur during the fall, a time when air pollutants are at generally low levels in the state. We report on an in-depth analysis of data for those fall peak periods; this is an exploration as to whether environmental variables might explain this temporal variation.

METHODS

Our preliminary analyses examined secular trends, seasonality, other sources of autocorrelation, and potentially confounding meteorological and indoor air pollution factors for NJ children's asthma hospital admissions. We found the meteorological data to be highly autocorrelated with pollen and mold data. Thus, meteorological data, although thoroughly examined, are not reported here.

Admissions Data

Hospital admissions data represent severe cases of asthma, whereas outpatient data are more likely to reflect less severe cases of the disease. Although it would be preferable to use both inpatient and outpatient data for this analysis, a statewide data set reflecting outpatient visits does not exist. Furthermore, most outpatient data sets (emergency room,

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clinic, and physician's offices) are proprietary and generally not made available to researchers, primarily as a result of the Health Insurance Portability and Accountability Act. Inpatient data, in contrast, are statewide; an anonymous data set can be obtained under Institutional Review Board stipulations. Therefore, we obtained an anonymous inpatient data set for use in this study.

We examined NJ hospital admissions data (UB-92) for NJ residents for the years from 1993 to 1995, as that period drew public health attention as a result of surging rates of children's asthma hospital admissions. As part of the Uniform Bill Patient Summary (inpatient) N.J.A.C. 8:31B-2 Regulations, the NJ Department of Health and Senior Services collects and processes information from 127 acute care hospitals annually, using a UB-92 Output File. Each hospital discharge case includes the patient's sex, race, admission date, and diagnosis. Because the admission date for each patient record is a confidential field, it was available after the NJ Department of Health and Senior Services Internal Review Board approved its use in this research.

There are about 1.2 million hospital admissions in NJ acute care hospitals every year. Of these, approximately 16,000 hospital admissions list asthma as a primary diagnosis, using International Classification of Disease (ICD) codes 493.0, 493.90, and 493.91. A limitation of the data set is that there are no hospital patient records for NJ patients who used hospital services outside of the state. A further limitation is that the data set does not have information on readmissions that are due to asthma. This means that trends reflecting changes in the frequency of recurrent asthma hospitalizations cannot be determined and that patients with multiple hospital admissions could potentially inflate high hospital admission rates for asthma.

Air Pollution Data

We obtained air pollution data for the same period from the US Environmental Protection Agency (EPA) Region II, compiled from the EPA's Aerometric Information Retrieval System database. The data were gathered by various monitoring stations throughout the state by the NJ Department of Environmental Protection. The variables we selected for analysis were ozone; nitrogen dioxide (NO₂); particulates, in the form of particulate matter < 10 µm in diameter (PM₁₀); and sulfur dioxide (SO₂). These variables are routinely used in air pollution analyses and reported in particles per billion. For each air pollutant, we had data collected at different time intervals. For example, ozone is a potential problem only in the late spring, summer, and early fall months, so that is the only time that data for ozone are collected.

Pollen and Mold Data

Cherry Hill, NJ, was the only location that had complete pollen data available at the time of this study. Officials at 2 other sites collect similar data, but the data are not complete and were not readily available. Researchers at the Asthma

Center at Cherry Hill collected pollen data by using a volumetric air-sampling procedure performed with the Burkard Trap Device (Burkard Manufacturing Co. Ltd, Hertfordshire, England) sampling over a 24-hour period. Pollen and mold counts measure the amount of airborne allergens present per cubic meter of air. The Asthma Center reports pollen as particles per billion and mold spore counts as particles per cubic meter for the Delaware Valley, Monday through Friday, from March through October of each year.

To address the concern about whether pollen collected from a single site could represent the entire state's aeroallergen burden, we compared temporal variations in asthma hospital admissions in the Cherry Hill area with those for the rest of NJ during the study period. As the 2 groups showed similar temporal patterns in asthma hospital admissions, we allowed the single-site collection data to represent the general aeroallergen burden for the state. We replaced missing data with 7-day centered moving averages. For our analyses, we used daily tree (a combination of *Acer*, *Alnus*, *Betulaceae*, *Carya*, *Cupressaceae*, *Fagus*, *Fraxinus*, *Juglans*, *Liquidambar*, *Morus*, *Olea*, *Pinus*, *Platanus*, *Populus*, *Quercus*, *Salix*, *Tilia*, and *Ulmus*), grass (*Gramineae*), weed (a combination of *Artemisia*, *Chenopodium/Amaranthus*, *Compositae* excluding ragweed, *Cyperaceae*, *Plantago*, *Rumex*, *Typha*, and *Urtica*), and ragweed (*Ambrosial/Franseria*) pollen counts. We also used daily mold counts (a combination of *Alternaria*, *Ascospores*, *Basidiospores*, *Botrytis*, *Cercospora*, *Cladosporium*, *Curvularia*, *Drechslera/Helminthosporium*, *Epicoccum*, *Fusarium*, *Nigrospora*, *Oidium*, *Periconia*, *Peronosporales*, *Pestialotia*, *Pithomyces*, *Polythrincium*, *rusts*, *smuts*, *Stemphylium*, *Torula*, other, and unidentified).

According to research on the priming effect of pollen allergens,^{12,13} initial levels of ragweed or weed pollen may not be clinically significant until they reach a threshold. Although the sensitization process may begin as early as infancy,¹⁴ individual children may respond to pollen levels in a variety of ways. They may require not only a threshold exposure but also a lag time to become symptomatic. To allow for this possibility, we created additional variables reflecting 1 to 3 days of exposure (lag terms) for the pollen variables.

Statistical Analyses

We examined children's daily hospital admissions for a seasonal pattern. We created a 7-day moving average to smooth variations in data. We selected the annual peak periods for children's asthma hospital admissions (August 15–October 31) as the best time to explore the relationships between environmental triggers and daily asthma hospital admissions. We examined relationships among the independent environmental variables by using Pearson cross-correlation analyses. We explored the relationships between the number of asthma hospital admissions and the environmental variables by using multiple regression.

RESULTS

Children's Hospital Admissions for Asthma

Between 1993 and 1995, there were 17,905 asthma hospital admissions for children aged 0–14 years. Among these cases, 3 were newborn-related hospital admissions; we dropped them from further analyses ($N = 17,902$ cases). The number of admissions was highest during September and October of each year (Figure 1). According to a centered moving average (7-day window), the lowest number of hospital admissions occurred on August 6, 1993 ($M = 4$ per day for 7 days), and the largest occurred on September 24, 1993 ($M = 53$ per day for 7 days). On September 27, 1993, alone, there were 59 childhood asthma hospital admissions in the state. We later used the 7-day moving average for the multiple regression analyses (see Figure 2).

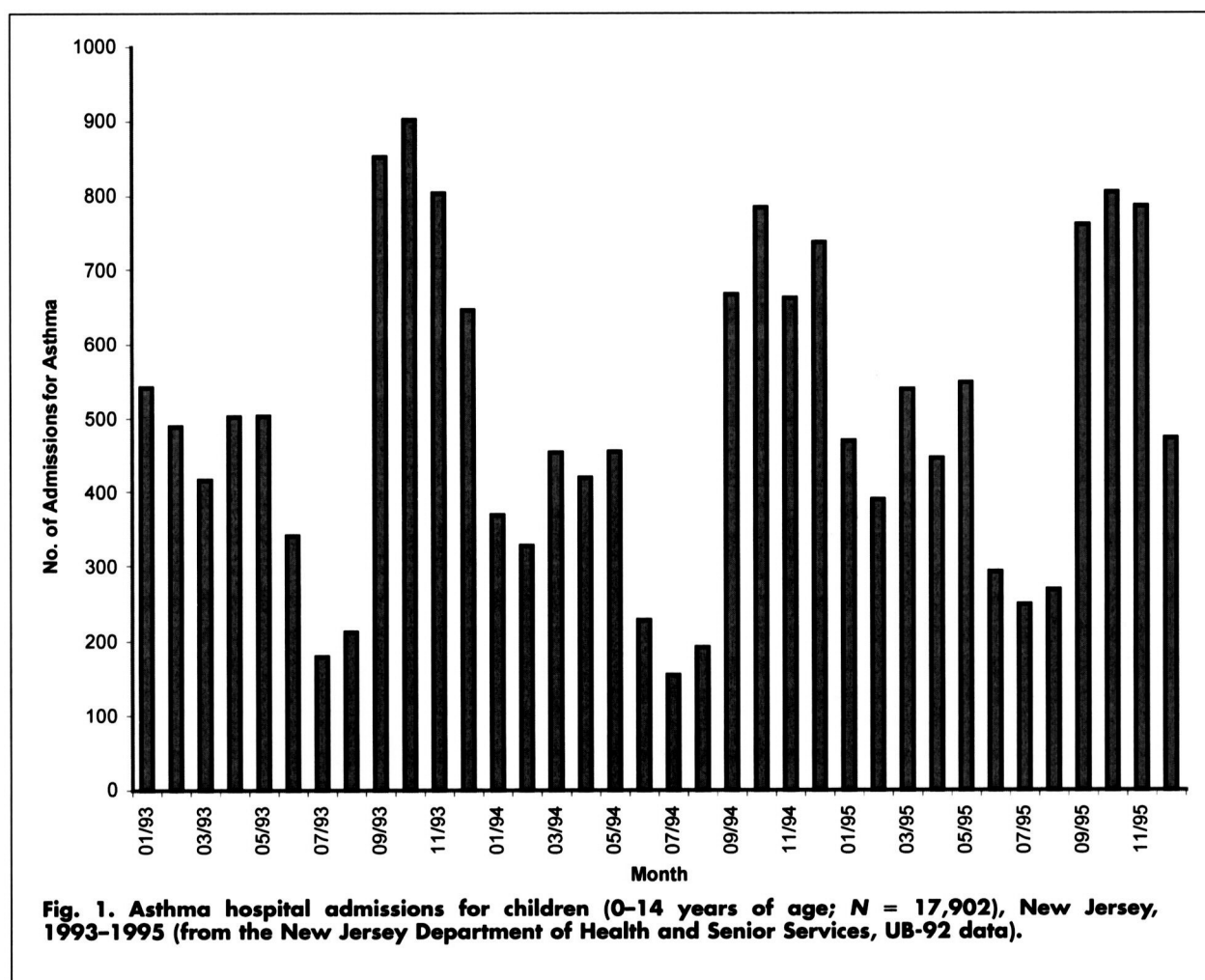
Air Pollution

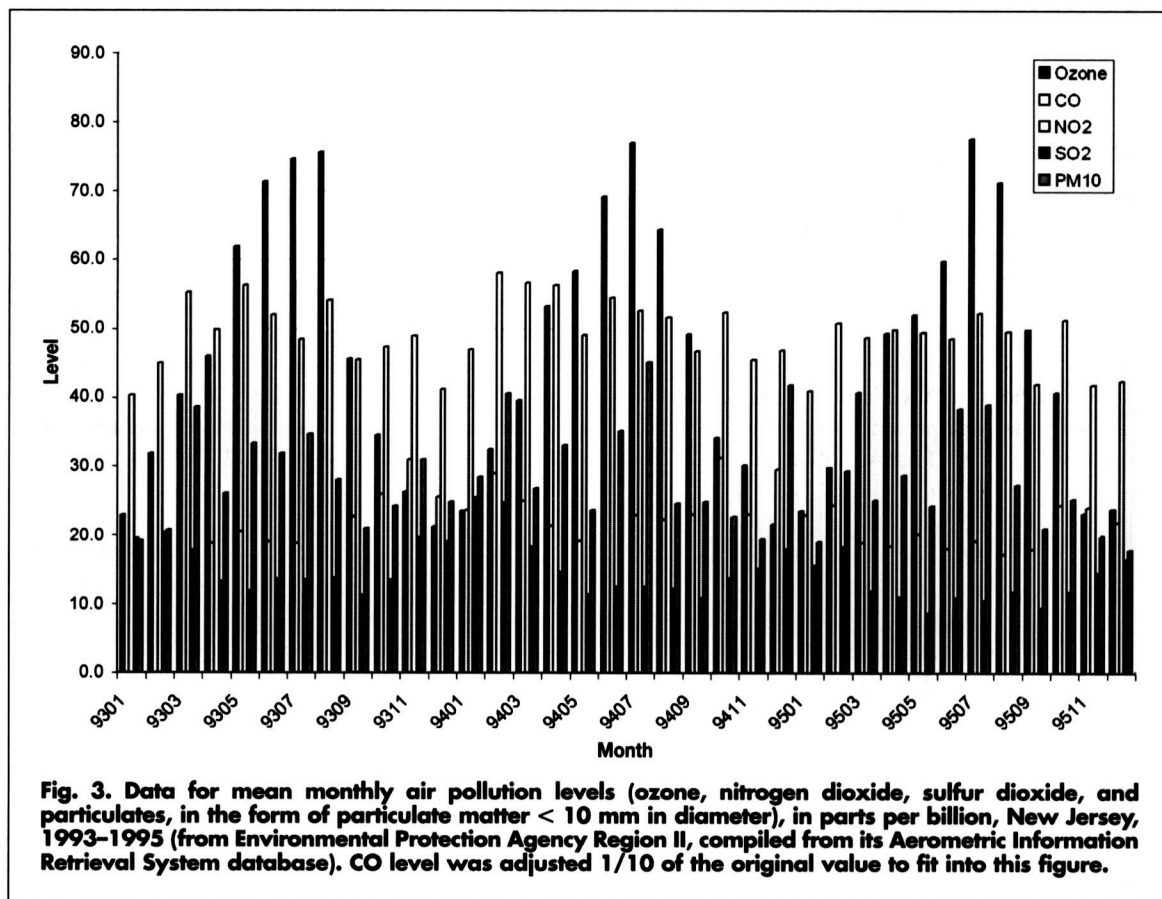
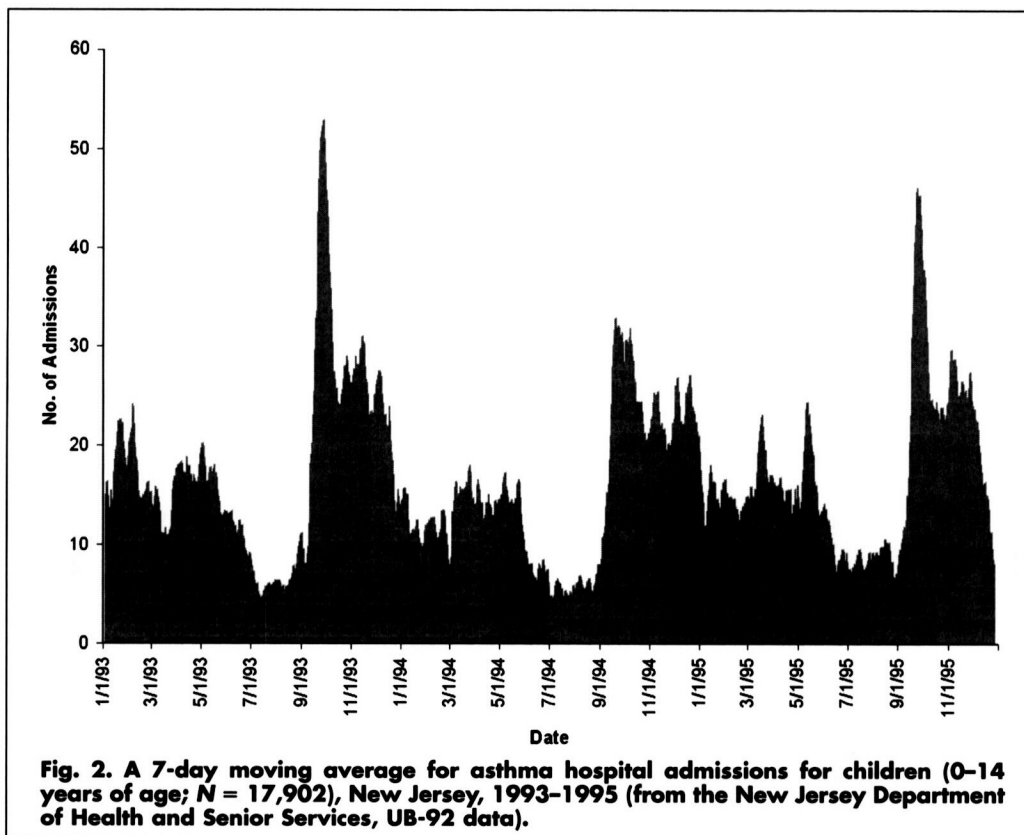
Air pollution data for 1993 through 1995 showed different seasonal patterns for the different pollutants. Maximum hourly ozone pollution levels were highest during the sum-

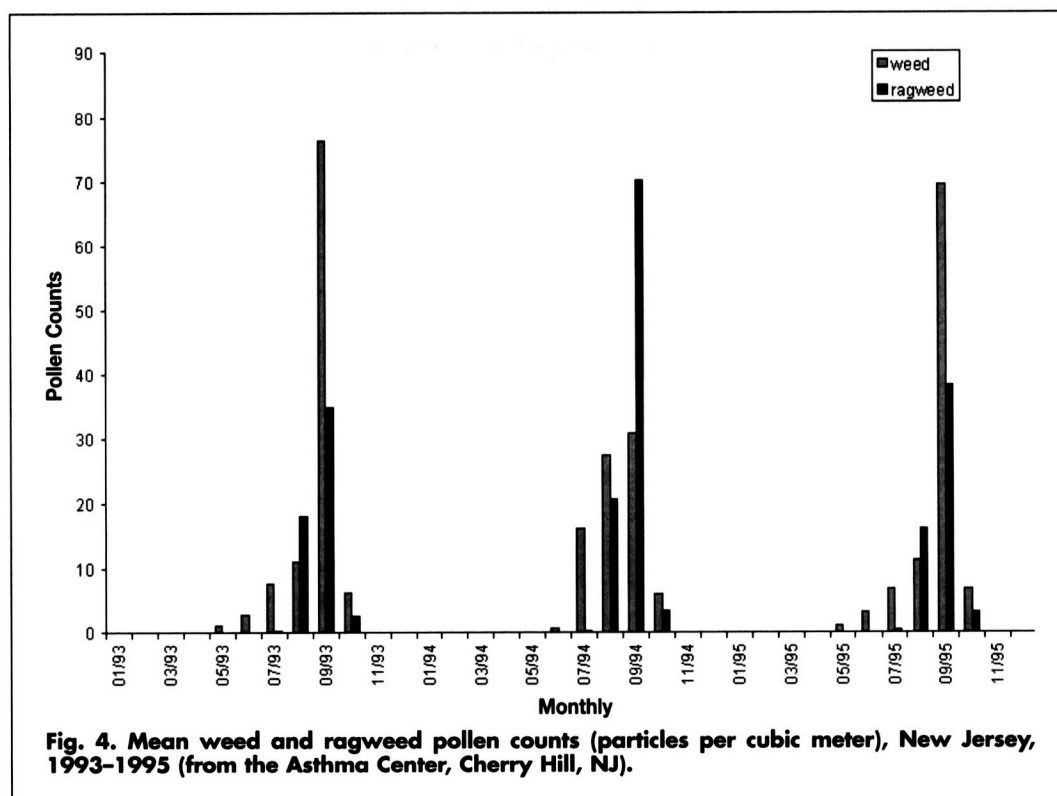
mer. Because ozone is a secondary air pollutant produced through a photochemical process that requires hot temperatures, we expected that there would be high ozone levels during the summer season. NO_2 levels were higher during spring and summer seasons; they were lower during fall and winter. Over the study period, SO_2 levels began to increase significantly during late September and to decrease during early March. SO_2 levels were highest in January and February of 1994, peaking in NJ on February 18, 1994. Daily PM_{10} varied throughout the year, showing no seasonal pattern (Figure 3).

Pollen Counts

We examined tree, grass, weed, and ragweed pollen levels for patterns, but we used only weed and ragweed pollen in our regression analyses because tree and grass pollen had no activity during fall, which is the peak season for NJ children's asthma hospital admissions. The weed pollen season starts during May of every year in NJ; it peaks during October. Figure 4 shows that the daily weed pollen count is highly seasonal. The dates of September 20, 1993, and September 20, 1995, had the highest daily weed pollen counts ($n = 357$).







In NJ, the ragweed pollen season starts during May of every year, but it is unnoticeable until August. Ragweed pollen counts surge each August and peak each September. Figure 4 shows that daily ragweed pollen counts were highly seasonal during the 3-year study period. September 5, 1994, had the highest ragweed pollen count per day ($n = 255$). Ragweed pollen count data were not collected during November through February of each year because there is no pollen activity during that time.

Correlation Results

We calculated Pearson correlation coefficients among variables to examine how each variable is related to every other variable during the peak period. Table 1 shows correlation coefficients among air pollutants, pollen, and daily hospital admissions during the study period. If 2 independent variables are more correlated with each other than either is to the dependent variable, then multicollinearity is indicated, and we would consider dropping one of the variables in a multiple regression formula. Ozone, NO_2 , SO_2 , and PM_{10} all show significant negative correlation coefficients with daily asthma hospital admissions. This negative association is most likely due to each variable's seasonality. For example, ozone has a strong negative correlation coefficient ($r = -.735$) with asthma admissions during the fall period. Ozone levels decrease significantly after July because ozone is produced by a photochemical process that requires high temperatures and bright sunny days. During the study period, temperature and ozone levels drop as the season changes from

summer to fall. Ozone had high correlation coefficients with NO_2 ($r = .480$) and PM_{10} ($r = .661$).

Whereas weed pollen showed a positive correlation coefficient with daily asthma hospital admissions ($r = .132$), ragweed showed a negative one ($r = -.232$). Weed pollen had a high correlation coefficient with ragweed ($r = .380$). For the regression model, we chose ozone, weed, and ragweed pollen variables.

Regression Results

On the basis of our exploratory analysis, we included 3 independent variables in our initial model: ozone, weed, and ragweed. The initial model explained 34.1% of the variation in children's overall asthma hospital admissions, adjusted $R^2 = .341$, $F(3, 272) = 48.392$, $p < .001$, and ozone itself explained 24.6% of the variation during the fall peak period. All 3 variables had significant ($p < .0001$) beta correlation coefficients; however, these results were negative for both ozone and ragweed. The negative results for ozone can be attributed to the fact that ozone itself is low during the peak of children's asthma hospital admissions in September and October. The negative results for ragweed may be more complex; we explore them in the discussion.

As weed pollen had the only positive correlation coefficient with asthma hospital admissions during the study period, we examined it separately. We examined 0 to 3 lag days of weed pollen counts with daily asthma admissions. All 4 of these lag variables were highly correlated with each other, with the 3-day lag term yielding the highest correlation

Table 1.—Correlation Coefficients Among New Jersey Air Pollutants, Pollen, and Daily Hospital Admissions During the Study Period

Pollutant or pollen	No. of admissions	1	2	3	4	5	6
Total							
Pearson correlation	1	−0.537**	−0.136*	−0.021	−0.236	0.132*	−0.232**
Significance	0	.024	.724	.114	.029	0	
n	276	276	276	276	46	276	276
1. Avg. ozone							
Pearson correlation	−0.537**	1	0.48**	0.287**	0.661**	−0.023	0.154*
Significance	0	0	0	0	.709	.01	
N	276	276	276	276	46	276	276
2. Avg. NO ₂							
Pearson correlation	−0.136*	0.48**	1	0.668**	0.604**	−0.096	−0.07
Significance	.024	0	0	0	.112	.243	
n	276	276	276	276	46	276	276
3. Avg. SO ₂							
Pearson correlation	−0.021	0.287**	0.668**	1	0.684**	−0.176**	−0.158**
Significance	.724	0	0	0	.003	.009	
n	276	276	276	276	46	276	276
4. Avg. PM ₁₀							
Pearson correlation	−0.236	0.661**	0.604**	0.684**	1	−0.085	−0.131
Significance	.114	0	0	0	.576	.384	
n	46	46	46	46	46	46	46
5. Weed (M)							
Pearson correlation	0.132*	−0.023	−0.096	−0.176**	−0.085	1	0.38**
Significance	.029	.709	.112	.003	.576	0	
n	276	276	276	276	46	276	276
6. Ragweed (M)							
Pearson correlation	−0.232**	0.154*	−0.07	−0.158**	−0.131	0.38**	1
Significance	0	.01	.243	.009	.384	0	
n	276	276	276	276	46	276	276

Note. The study period is from August through October, every year, from 1993 to 1995. The table shows two-tailed significance. NO₂ = nitrogen dioxide; SO₂ = sulfur dioxide; PM₁₀ = particulates, in the form of particulate matter < 10 μm in diameter.

*Correlation is significant at the .01 level.

**Correlation is significant at the .05 level.

coefficient ($r = .247$) with asthma hospital admissions. A final model using only the 3-day lag weed pollen count explained 5.8% of the daily asthma hospital admissions for children, adjusted $R^2 = .058$, $F(1, 274) = 17.830$, $p < .001$. The following model implies that an increase of 13 counts of weed pollen (particles per cubic meter) increased the daily asthma hospital admissions for children by 1 during the study period:

$$\text{Daily asthma admissions}_t = 0.07489 \times \text{Weed}_{t-3} + 17.663.$$

Seasonal Adjustment

Figure 5 shows strong upward trends in both the exposure variables and asthma admissions during the 1993 fall season. Similar findings were demonstrated for 1994 and 1995. It is possible that these associations might be confounded by other strong seasonal factors that we may not have accounted for in this analysis. To test that possibility, we used a generalized additive Poisson regression model to remove the seasonal effect. We used an overdispersed Poisson model specifically in which the daily asthma count can be represented as the following:

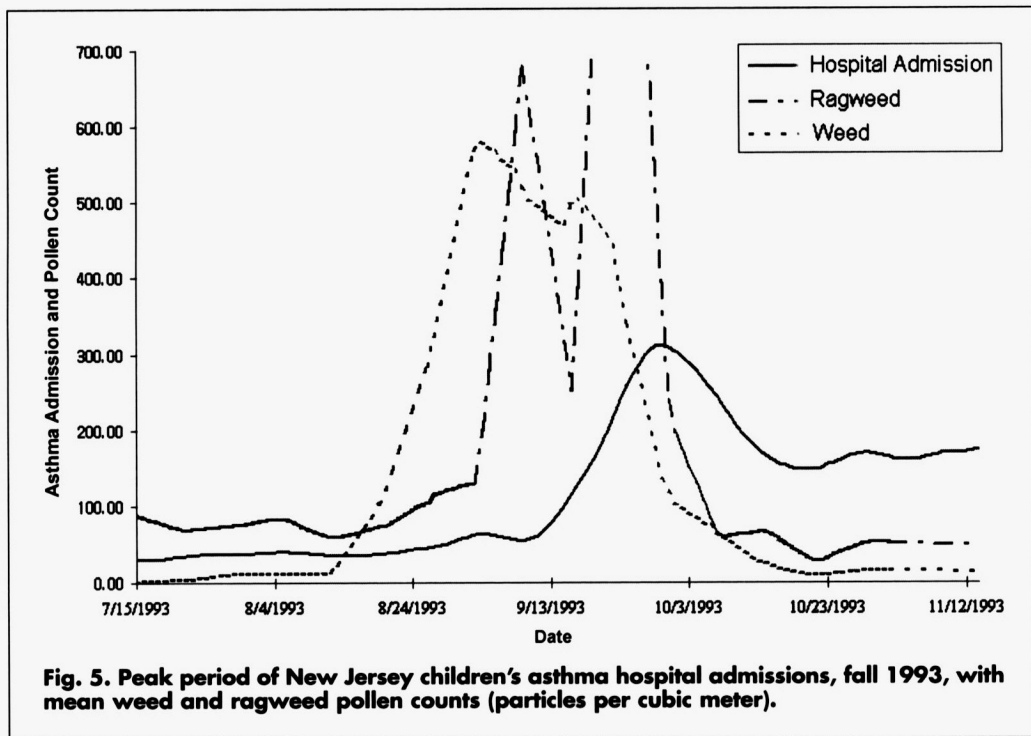
$$\log E[\text{daily asthma admissions}]_t = \text{intercept} + \beta_1 \text{weed}_t + \beta_2 \text{ragweed}_t + \beta_3 \text{ozone}_t + \text{smoothing spline}(\text{time}).$$

As suggested by Peng et al.¹⁵ and Tobias et al.,¹⁶ we employed stringent convergence parameters (0.00001) to avoid possible biased regression coefficients and standard errors. We performed our analysis with S-Plus 7 (Insightful Corporation, 2005). As the coefficients of the model showed similar results to those in the initial regressions, it is unlikely that other seasonal confounders affected our results.

COMMENT

This analysis of seasonal differences in children's asthma hospital admissions during the period from 1993 to 1995 in NJ determined that the early fall season accounts for almost 40% of these admissions. Summer accounted for approximately 12%. Researchers have examined seasonal variations in asthma attacks and asthma hospital admissions, but most of the research focused on explaining daily fluctuations in asthma prevalence and severity by using air pollution data.^{16–18} Experts in several other epidemiological studies found significant associations between ozone air pollution and daily hospital admissions for respiratory disease.^{16,18–22}

Despite at least one report about the impact of ozone on asthma prevalence in children,⁷ we found that hospital



admissions for childhood asthma were lowest in NJ during the summer months. This is contrary to what might be expected if ozone was a significant factor for explaining children's asthma hospital admissions. Over the 3 years of data that we examined, ozone had a negative relationship with children's daily asthma hospital admissions, despite the fact that there were a number of days when the ozone health standard was exceeded during the study years and despite the fact that ozone remains NJ's most pervasive air quality problem. Furthermore, we did not find a significant positive relationship between other types of air pollution and peak periods of children's asthma hospital admissions; the impact of air pollution variables during the peak period of children's hospital admissions for asthma was minimal.

NJ has notoriously high levels of ragweed and weed pollen, and conditions for pollen and other allergens may be somewhat similar to those in London.²³ The National Allergy Bureau's *Pollen and Mold Report*²⁴ documents high weed and ragweed pollen counts in the region during the last weeks of September of each year. These high weed and ragweed pollen counts roughly correspond to the high proportion of children's asthma hospital admissions. Because of these parallels, we expected that ragweed and weed pollen would be significant predictors of children's asthma hospital admissions. Only weed pollen, however, was significantly associated with children's hospital admissions for asthma. A partial explanation for the results may be that ragweed and weed pollens have different temporal patterns, as ragweed pollen peaks approximately 15 days earlier than does weed pollen (see Figure 4). Children's daily asthma hospital admissions began to increase after the ragweed pollen count

peaked and the weed pollen count reached a high level. After both pollen counts passed their peaks, the daily asthma hospital admissions kept increasing until ragweed and weed pollen counts became significantly low.

According to research on the priming effect theory of pollen allergens, initial levels of ragweed or weed pollen may not be clinically significant until they reach a threshold. Once people with asthma are triggered for exacerbation of their asthma by strong pollen counts, they may continue to be affected by even minor pollen levels. Therefore, some of the temporal variation in daily asthma hospital admissions for children during the fall may occur because exposures reach a threshold effect of ragweed and weed pollen counts. This possibility requires further detailed investigation.

Other potential explanations for the seasonal surge in children's daily asthma hospital admissions include the fact that as temperatures fall, schools turn on their mostly forced-air heating systems that have lain dormant all spring, summer, and early autumn. Sensitized children are then exposed to large amounts of allergens, especially dust mites, residing in the ductwork. To explore the possibility that the peaks were driven by exposure to a bolus of dust mites circulating in school heating ducts, we contacted several elementary schools in NJ for their school policy regarding heating. Maintenance crews indicated that they turn on the heat when outside temperatures fall below 60°F. An examination of minimum temperatures in NJ for the study period showed that temperatures fell below 60°F many weeks later than the asthma peak season. This means that forced-air heating in public schools was an unlikely explanation for the asthma peak during the study period.

Another explanation offered is that there is a significant correlation between viral respiratory infection and asthma.^{1,25-28} For example, Johnston et al¹ state that upper respiratory viral infections are strongly associated with children hospital admissions. Rhinoviruses in particular can cause severe coughing, wheezing, and obstruction to airflow. Rhinovirus illness peaks in September, after school opens, and in the spring.^{1,28} The possibility exists, therefore, that the fall asthma peak can be explained simply by exposure to rhinovirus. Although no population-based data exist to test this possibility, it is notable that the asthma peak is 3 weeks into the school year, later than might be expected if rhinovirus was the key to understanding children's hospital admissions for asthma. In the future, researchers should examine whether the viral infections and allergic inflammation act synergistically to explain children's asthma hospital admissions.²⁷

Asthma and Allergy

Different pollen types have their own antigenicity, or levels of exposure required to trigger an allergic reaction.^{14,15} Individuals also vary in their response to allergens. Pollen and mold counts may vary in their clinical significance depending on time and place. The threshold level to provoke asthma symptoms may also be affected by a priming effect of other allergens just before the season begins. According to Jelks,¹² a ragweed pollen count of 0–20 particles per cubic meter of air per 24-hour average is a low exposure; it would elicit symptoms only in individuals who are extremely allergic to ragweed. A ragweed pollen count of 20–200 particles per cubic meter is considered a medium count; it would elicit symptoms in most people with ragweed allergy. A ragweed pollen count of greater than 200 particles per cubic meter is a high count that would cause symptoms in all individuals with clinical sensitivity to ragweed pollen. Connell¹³ found that, after individuals were given repeated intranasal challenges with ragweed pollen on successive days, fewer grains elicited symptoms. He observed that fewer grains would cause congestion in midseason and at the end of the season than before the season. It took 2 months before the preseasonal dose was tolerated again by the individuals in Connell's study. Although mold exposure is a known asthma trigger, this analysis found no association between asthma admissions and outdoor mold spore counts.

Conclusion

By knowing the cyclical peak or surge of asthma hospital admissions in relation to environmental triggers, health-care professionals can be prepared for the increase in asthma patients and warn asthmatic children about the upcoming pollen season. Asthmatics may benefit from more education or public information during fall, when asthma triggers are high and the number of asthma hospital admissions is high.

We found that children's asthma hospital admissions in NJ are lowest in summer, although ozone air pollution is the highest during that season. Although many researchers have examined the relationship between ozone and asthma symptoms, there may be a need for further research in examining the relationship between pollen and asthma symptoms. The findings in this study are confined to NJ; experts should evaluate other areas with different annual climate types.

Experts crafting predictive models for asthma hospital admissions should take into account the threshold effect and explore appropriate lag times for environmental variables of interest. For instance, a high pollen count for initial exposure may not trigger asthma symptoms; however, a low level of pollen exposure, after a person becomes sensitized, might trigger asthma symptoms. Researchers should examine more fully how different levels of pollen exposure affect the person with asthma at different time periods. In terms of reducing asthma hospital admissions for children, a better designed pollen-related warning system and education about the relationship between pollen and asthma symptoms could be crucial in preventing at least some asthma hospital admissions.

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