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Effects of Ambient Pollen Concentrations on Frequency and Severity of Asthma Symptoms Among Asthmatic Children

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Abstract

Background—Previous studies on the associations between ambient pollen exposures and daily respiratory symptoms have produced inconsistent results. We investigated these relationships in a cohort of asthmatic children, using pollen exposure models to estimate individual ambient exposures.

Methods—Daily symptoms of wheeze, night symptoms, shortness of breath, chest tightness, persistent cough and rescue medication use were recorded in a cohort of 430 children age 4-12 years with asthma in Connecticut, Massachusetts and New York. Daily ambient exposures to tree, grass, weed and all-type pollen were estimated using mixed effects models. We stratified analyses by asthma maintenance medication and sensitization to grass or weed pollens. Separate logistic regression analysis using generalized estimating equations were performed for each symptom outcome and pollen type. We adjusted analyses for maximum daily temperature, maximum 8-hr average ozone, fine particles ($PM_{2.5}$), season and antibiotic use.

Results—Associations were observed among children sensitized to specific pollens; these associations varied by use of asthma maintenance medication. Exposures to even relatively low levels of weed pollen (6-9 grains/m^3) were associated with increased shortness of breath, chest tightness, rescue medication use, wheeze, and persistent cough, compared with lower exposure among sensitized children taking maintenance medication. Grass pollen exposures ≥2 grains/m^3 were associated with wheeze, night symptoms, shortness of breath and persistent cough compared with lower exposure among sensitized children who did not take maintenance medication.

Conclusion—Even low-level pollen exposure was associated with daily asthmatic symptoms.

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Inhaled aeroallergens such as pollen, are an established cause of allergic respiratory symptoms.[1] Asthmatic symptoms in turn are a major part of the morbidity from allergic respiratory illness in the United States, accounting for more than $6.2 billion annually in direct costs.[2] Consequently, many studies have examined the association between aeroallergens and indicators of asthma and asthma exacerbations. Both indoor and outdoor aeroallergens have been linked to asthma. However, the assessment of daily, individual exposures has been limited.

Children can be particularly susceptible to allergens due to immature respiratory and immune systems, as well as indoor and outdoor activities that can differ from adults.[3] Previous studies have found associations between indoor allergens and asthmatic symptoms of children, including infants.[4-6] Generally, indoor exposures are measured via volumetric spore traps placed throughout the home. Due to cost and the burden on study participants, measurements are usually taken at few time points and do not capture day-to-day variability.

Exacerbations of asthma have also been linked to ambient pollen concentrations. However, results of previous studies have been inconsistent. For example, weed pollens demonstrated both positive[7-8] and negative[9] associations with asthma. Differences in the types and composition of pollens, study populations (including sensitization profiles), and study design, may contribute to inconsistent findings of previous studies. Another contributing factor may be limitations in the assessment of pollen exposures. Studies have estimated ambient exposures by averaging values from one or a few aeroallergen monitors. Such regional or population-level estimates do not address spatial variability.

We sought to estimate how genus-specific pollens (tree, grass, and weed pollen), using individual-level, daily exposures, affect risk of respiratory symptoms for an asthmatic cohort, considering sensitization to specific pollens when possible. Daily ambient concentrations of total pollen and genus-specific concentrations were estimated for the area around the residence of each study subject.

Methods

Cohort

Study subjects were 466 children (ages 4-12 years), enrolled in a prospective study of asthma severity conducted by the Yale Center for Perinatal, Pediatric and Environmental Epidemiology.[5,10] Subjects were enrolled from 2000 through 2003 from families living in Connecticut, south-central Massachusetts and New York State. Eligible subjects were younger than 12 years at the time of enrollment, had physician-diagnosed asthma, and experienced asthma symptoms or used asthma medication during the year prior to enrollment. We restricted the analysis to 430 subjects who completed an exit interview and who lived primarily within the northeastern U.S. throughout follow-up, because the models to estimate ambient pollen exposures in this study were developed specifically for this region.[11]

Each child's mother completed a questionnaire at enrollment, including demographic information and medical histories. Mothers also recorded daily asthma symptoms and medication use on study calendars, and reported this information through monthly telephone interviews. Asthma symptoms included wheeze, night symptoms (general asthma symptoms that occur at night (a time when airways can narrow due to lying down)), shortness of breath, chest tightness and persistent cough. Data on asthma medication included rescue medication (short-acting beta2-agonists) and asthma maintenance medication (long-acting beta2-agonists, cromolyn sodium, leukotriene inhibitors, theophylline or steroids).

Blood samples were provided by 319 (74%) subjects for an allergen-specific IgE panel that included grass and ragweed. Serum was analyzed using the UniCAP® system. Subjects were considered to have positive sensitization if serum IgE was 0.35 kU/L or greater. We used ragweed sensitization as a measure of sensitization to all weed pollen because ragweed represents the majority of weed pollens in the study area. The study was approved by the Yale University Human Investigation Committee, and the mother of each participating child gave informed consent.

Ambient Allergen Assessment

We estimated daily ambient concentrations of total pollen (all pollen genera combined), and separate concentrations for tree, grass and weed pollen, at each subject's home, using a mixed-effects model previously developed.[11] This exposure model allows for individual-level estimates of total and genus-specific pollen for each study subject, incorporating daily and seasonal weather, land cover around each subject's home, day of pollen season, and indictor of peak pollen periods. These models are described in detail elsewhere.[11] The model performs best at non-extreme portions of the distribution (e.g., concentrations other than absent (i.e., no pollen) or counts > 95th percentile).[11] Therefore, we assessed pollen exposures by quintiles. Total pollen in the lowest two quintiles was estimated by the model with approximately 85% accuracy, and in the highest quintile with 65% accuracy. Model accuracy for genus-specific pollen concentrations was even higher.[11]

Pollen seasons were defined as beginning on the day on which 1% of the cumulative yearly pollen of a certain type had been measured, and ending on the day on which 99% of the cumulative yearly pollen had been measured.[12-13] We estimate peak pollen periods (based on methods described by Smith and Emberlin[14]) as either the date from the first to the second inflection point on a cumulative distribution curve or 85% of the total pollen count for a season, whichever came first. For each subject's home, we calculated pollen-season start and end dates and peak pollen periods by a distance-weighted average of the two closest allergen monitoring stations.

Land-cover information was obtained from the United States Geological Survey Land Cover Institute, National Land-cover Database 2001. This database identifies 16 classes of land cover at 30-meter resolution: open water, perennial ice/snow, developed (open space, low intensity, medium intensity, high intensity), barren land, deciduous forest, evergreen forest, mixed forest, shrub, grassland/herbaceous, hay/pasture, cultivated crops, woody wetland, and emergent herbaceous wetland. We calculated the percent of each land-cover classification around each subject's home for radii selected to maximize the association between land-cover and seasonal loads of each pollen type.[11] Estimations of all-type and grass pollen concentrations used a 100km radius, estimates of weed pollen used a 50km radius, and estimates of tree pollen used a 20km. Land cover around each subject's home was classified into similar groups using discriminant analysis.[11]

These exposure models generated daily estimates for each study subject based on their residence. We calculated estimates for each day and study subject for all pollen genera combined, and separately for tree, grass and weed pollen. This method permits spatial and temporal heterogeneity of exposure among individual study subjects. Spatial variation would be obscured by more usual methods, such as exposure based on a regional average.

Criteria Air Pollution Data

Daily ambient monitoring data for U.S. Environmental Protection Agency (EPA) criteria pollutants were obtained from the EPA Air Quality System Database.[15] The pollutants includednitrogen dioxide (NO_2), sulfur dioxide (SO_2), ozone (O_3), and particulate matter with aerodynamic diameter ≤2.5 μm ($PM_{2.5}$). These pollutants have been associated with allergic respiratory symptoms.[6,10,16-18]

Daily exposures for criteria pollutants were assigned to each child based on the closest monitor. We used the maximum 8-hour average as the metric for O_3, and the 24-hour average for other criteria air pollutants — which correspond to the metrics used in U.S. regulations. The study region contained 17 monitors measuring O_3, 18 measuring $PM_{2.5}$, 8 measuring NO_2 and 8 measuring SO_2. Subjects lived an average of 10.4 km (interquartile range [IQR]=10.4 km [range=0.2-39.1km]) from the nearest O_3 monitor. On average, subjects lived 11.6 km from the nearest monitor measuring $PM_{2.5}$ (IQR=11.9 km [range=0.2-39.1km]). For NO_2 and SO_2 the average distance between a subject's home and nearest monitor was 21.0km (19.6 km [0.6-56.5 km]) and 21.1km (18.8km [0.6-56.5 km]), respectively.

Weather Data

We obtained the following weather data from the National Climatic Data Center[19] :daily values of minimum, maximum and mean temperature; dew point temperature; precipitation; and wind speed. Weather data were collected from 14 weather stations throughout the study region and were assigned to study subjects based on the nearest monitor. All weather variables were used in the development of models to estimate ambient pollen exposures at each subject's home.[11] Models examining the association between pollen exposures and asthmatic symptoms were adjusted for maximum daily temperature.

Statistical Analysis

Logistic regression models using generalized estimating equations with autoregressive lag 1 (AR(1)) correlation structure were used to analyze associations between pollen exposures and daily asthma symptoms. This approach has been previously used in analysis involving this cohort.[10] We stratified analyses by severity of asthma, based on whether a child ever used asthma maintenance medication during follow-up.[10] A total of 172 children (40%) did not use maintenance medication. Global Initiatives for Asthma guidelines (GINA) define a 5-category severity score based on symptom frequency and medication use.[20] In an effort to avoid using outcome measures to determine asthma severity we chose to classify asthma severity based on use of maintenance medication, rather than GINA score. We were able to analyze children sensitized to grass (n=83; 26%) and to weed pollen (n=70; 22%) individually for those specific exposures.

Separate logistic regression models were created for each respiratory symptom, which includes experiencing any respiratory symptom (i.e., any of the previously listed symptoms) on a given day. Use of short-acting beta2-agonist, a rescue medication, was considered as a separate outcome. Exposure variables were total pollen, tree pollen, grass pollen and weed pollen. Pollen exposures were categorized into quintiles. Models were adjusted for criteria air pollutants, maximum daily temperature, season and use of antibiotics. These factors have been associated with respiratory symptoms in previous studies,[6,10,17-18,21] including some using this dataset. Criteria air pollutant exposures and maximum daily temperature were considered as continuous variables. Adjustment for maximum daily temperature has been considered in previous studies investigating ambient O_3 and $PM_{2.5}$ exposures and asthmatic symptoms in this cohort.[10] Same-day (lag 0) and previous-day (lag 1) exposures were examined.

Seasons were defined as March-May, June-August and September-October (other months are not within the pollen season) and entered into the model as binary variables. We limited analysis for each pollen type to days within the season for that particular pollen type.

Characteristics of the child that remain constant over the year of follow-up (such as race, sex and socio-economic status) were not included in the analysis because the form of the repeated-measures model considers each subject as their own control. A forward stepwise logistic regression with an $\alpha=0.05$ inclusion criteria was applied. Not all days had data for all criteria pollutants; however, our analyses were conducted on the subset of data for which all criteria air pollutants were available, regardless of which criteria air pollutants were included in the model, in order to ensure comparison with the same sample size and underlying data. We excluded periods during which a child was away from their residence for 2 or more weeks. Analysis of the association between daily pollen exposures and asthma symptoms was limited to the pollen season.

All odds ratios (ORs) and 95% confidence intervals (CIs) were calculated using SAS statistical software version 9.2 (SAS Institute, Inc., Cary, North Carolina).

Results

During the study period, the average pollen season was March 30 to October 2. The earliest pollen season started March 24 and the latest ended on October 10. As an example, the eFigure (http://links.lww.com) presents average daily concentrations of each pollen type across the entire study population for the year 2001. Patterns are similar for all study years (2000-2004). Tree pollen occurs in the spring to early June, grass pollen in the summer months, and weed pollen in the late summer to early fall. Table 1 summarizes distributions of total pollen; tree, grass and weed pollens; maximum temperature; and criteria pollutants. Tree pollens are the most abundant pollen type and reach the largest peak concentrations. Mean and peak concentrations of weed pollen tend to be higher than grass pollen.

The EPA air quality standards for NO_2 (0.053ppm annual) or SO_2 (0.14ppm 24-hr) were not exceeded at any monitor on any day over the 5-year study period. These were 34 days (4%) on which at least one monitor in the study area recorded 8-hr maximum O_3 concentrations exceeding EPA standards (0.08ppm), and 36 days (4%) on which 24-hour $PM_{2.5}$ standards (35 $\mu g/m^3$) were exceeded. High correlations were observed between NO_2 and both $PM_{2.5}$ (r=0.60) and SO_2 (r=0.71) and between $PM_{2.5}$ and O_3 (r=0.59) (results not shown).

Distributions of personal characteristics by use of asthma maintenance medication can be found in Table 2. Users (n=258) and non-users (n=172) were similar in age at time of enrollment, education of mother, and exposure to smoking. The majority of chidren were boys. Subjects were predominantly white, but also include Hispanic, black and Asian/other. Sensitization to grass and to ragweed pollen was higher among users of maintenance medication.

Table 3 summarizes the frequency of each asthma symptom and use of short-acting beta2-agonist (rescue medication) by pollen season and use of maintenance medication. Users of asthma maintenance medication experienced more days of any respiratory symptom than non-users (8.1 days compared with 1-5 days during an average pollen season of 165 days). Among users of maintenance medication, rescue medication was used on 5.7% of days in the pollen season. Persistent cough was the most prevalent symptom (median of 2.6% of days). . In contrast, more than 50% of non-users experienced no individual asthma symptom and used no rescue medication. The pattern of symptom frequency was similar during and outside the pollen season, although more symptoms occurred outside the pollen season (in winter). Daily information on respiratory symptoms and rescue medication use was available for more than 99% of days within the pollen season.

The frequency of any respiratory symptom varied by season, but not by day of the week. Seasonal variation was more pronounced among users of maintenance medication compared

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with non-users. The pattern of asthma symptom frequency (highest in winter and lowest in summer) is consistent with previous studies that have found associations between temperature and indicators of asthma.[22-23] Other issues, such as colds or other respiratory illnesses, may also be a factor in the seasonal pattern. To help incorporate the effects of illness, we adjusted for use of antibiotics.

Final logistic regression models included maximum 8-hr average O_3 and $PM_{2.5}$. Inclusion of other criteria air pollutants, NO_2 and SO_2, did not greatly affect the associations between pollen exposures and daily asthmatic symptoms. Allergic reactions may be exacerbated by exposure to air pollutants.[24-26] However, we did not observe any interaction between O_3 and pollen in their associations with respiratory symptoms (results not shown).

Among children taking maintenance medication, exposure to weed pollen was associated with any respiratory symptom (any of the examined symptoms on a given day), shortness of breath, and rescue medication use (Table 4). Comparing the highest quintile of weed pollen with the lowest, the likelihood of experiencing any respiratory symptom increased 23% (95% CI= 1.01-1.50) and the use of rescue medication increased 11% (1.02-1.21). Low-level exposure to weed pollen (second quintile) was associated with a 37% (1.08-1.74) increase in the likelihood of experiencing shortness of breath, compared with the lowest quintile. Likelihoods of experiencing any of these outcomes were consistently highest in the second-highest category of weed pollen rather than the highest. Among non-users of maintenance medication, there was little evidence in associations between weed pollen exposures and asthma symptoms, although power was reduced.

After stratification by sensitization to ragweed (i.e. weed pollen), the associations between weed pollen and symptoms or rescue medication were found only among those who were sensitized (Table 5). In addition, there was evidence of increased likelihoods of wheeze and persistent cough among the exposed children sensitized to weed pollen (Table 5).

Among non-users of maintenance medication, grass pollen was associated with increased likelihood of night symptoms and persistent cough (Table 4). An increased likelihood of night symptoms (OR= 1.69 [95% CI= 1.08-2.64]) was observed even at concentrations of grass pollen in the second quintile. The associations of grass exposure with persistent cough or night symptoms increased in a dose-dependent manner. As with weed pollen, associations between grass pollen and night symptoms or persistent cough were observed only among children sensitized to the allergen (Table 5). Grass pollen was most strongly associated with increased likelihood of any respiratory symptom, wheeze, shortness of breath and use of rescue medication among children sensitized to grass pollen who did not use maintenance medication (Table 5).

Exposure to higher levels of tree pollen was associated with an increase in likelihood of wheeze and shortness of breath among maintenance-medication users only. We lacked measurement of IgE specific to tree pollens to analyze whether a child's sensitization to tree pollens would affect the associations with respiratory symptoms, as was the case with the grass and weed pollen exposures.

Discussion

We explored the associations of ambient exposure to total pollen, as well as tree, grass and weed pollen, with respiratory symptoms and use of rescue medication among a cohort of asthmatic children. Most studies of allergens and asthma symptoms have focused on indoor exposures. These studies of outdoor allergens have usually used measurements from monitoring stations.[9,27-29] Our study expands on previous work by incorporating a modeling approach to estimate individual ambient pollen exposures in a prospective cohort design.

Estimates of individual-level ambient exposures, based on each child's place of residence, allow for a more detailed description of spatial variability in pollen exposures.

Few studies have examined ambient allergen exposures and individual asthma symptoms.[30-32] We are not aware of any previous study examining specific asthmatic respiratory events while providing individual estimates of ambient exposures. Strengths of this research include detailed data on daily respiratory symptoms and medication use. In addition, the population included only children with physician-diagnosed asthma, providing a study population that is pertinent from a risk-management and treatment perspective.

Our findings indicate that sensitive populations (i.e. maintenance-medication users sensitized to a particular allergen) experience elevated risk of any respiratory symptom, wheeze, shortness of breath, persistent cough and rescue medication use with exposures to weed pollen as low as 6-9 grains/m^3 (2^{nd} quintile). This level of exposure is defined as “low” by the National Allergy Bureau.[33] Odds of experiencing asthmatic symptoms also tended to decline with the highest quintile of exposure, which may indicate some behavioral modification when pollen concentrations are very high. Such behavior modification has been observed with high ambient O_3 concentrations.[34] The possibility of behavioral response to ambient pollen concentrations has not been explored, and we lacked information on the daily activity patterns of children necessary to access this. The exposure model is least accurate at the extremes of the pollen distribution, and the possibility of exposure misclassification is therefore a concern at the highest exposure category. However, misclassification is unlikely to explain a lower OR in the 5^{th} quintile of exposure compared with the 4^{th} quintile.

We were unable to investigate the effect of tree pollen on sensitized children due to lack of measurement of IgE specific to tree pollens. However, there was more evidence for an association between tree pollen exposures and respiratory symptoms among users of maintenance medication than among non-users. This may be because the users of maintenance medication are at higher risk for respiratory symptoms in general. Asthma exacerbations have been reported with exposure to both weed and tree pollens.[7-8,35] However, other studies have shown no association or negative associations.[9] Inconsistent findings are likely due to differences in the types and composition of pollens present, study populations (including sensitization profiles), and study design, as well as limitations in the assessment of pollen exposures.

We also observed that grass pollen increased likelihood of all respiratory outcomes among non-users of maintenance medication (the less severe asthmatic children) who were also sensitized to grass pollen. Our results are consistent with associations between grass pollen and asthma exacerbations shown in previous studies.[7,9,36] A possible explanation for associations among non-users and not among users of maintenance medication may be due to the timing of the grass pollen season. Grass pollens are most prevalent in the summer. During this time children with severe asthma may be less likely to engage in rigorous outdoor activities compared with less severe asthmatics.[37-38] Differences in lifestyle, including air conditioning use in the home, would also affect actual exposures of children. In addition, susceptibility to ambient air pollutants has been found to be lower among non-users of maintenance medication.[10] There is also a greater proportion of Hispanic and black children within the non-user group. Race is a factor that has been associated with higher indoor allergen exposures,[39] less frequent medication use and access to health care.[40]

Our findings are also pertinent to understanding future health burdens within the context of climate change. Increased pollen production has been associated with increased temperatures and CO_2 concentrations.[41] Even a slight increase in pollen production could substantially increase the number of days with exposures high enough to elicit an asthmatic response among sensitive children, given our finding of increased likelihood of asthmatic response at low levels of exposure. Moreover, higher temperatures may also lead to greater allergenic potency (i.e. allergenicity, of pollen[41]), which would further increase the risks associated with all levels of exposure, especially low levels. Although we did not observe any interactive effects between pollen and ozone, increasing air pollution levels may also exacerbate the effects of pollen on asthma symptoms.[24-26] These circumstances would indicate that sensitive populations may experience even greater frequencies of asthma symptoms if current climate change predictions hold.

Classification of asthma severity is a challenge. Previous research with this cohort concluded that the categorization of severity by use of maintenance medication reflects individual vulnerability to the health consequences of air pollution.[10] We classified asthma severity by use of maintenance medication, rather than GINA score or other combinations of symptom frequency and medication previously used to assess asthma severity,[5-6,10,42-43] because our outcome measures were respiratory symptoms and rescue medication use.[10] We observed that associations between specific pollen exposures and asthma symptoms differed by a child's asthma severity classification. Given these findings, further research investigating effect modification by asthma severity is warranted, including additional approaches of classifying severity.

This study focused on ambient pollen concentrations, which have been found to be higher than indoor levels.[44] Additional research could also incorporate indoor pollen measurements. Ideally, a study of indoor and outdoor allergen exposures would include data on daily activity patterns since children spend the majority of their time indoors.[3] Participation in outdoor activities may be even further limited among asthmatic children. Weather is also likely to influence children's activity and may be associated with ambient pollen concentrations. Additionally, home ventilation, use of air conditioning and other home characteristics may alter the relationship between indoor and outdoor pollen concentrations.

The results of this study indicate that risks of respiratory symptoms among asthmatic children with specific pollen sensitization are associated with pollen exposures even at low levels. A unique aspect and strength of this study is the assessment of individual ambient pollen exposures, and this approach to exposure assessment could be applied to other studies. These findings are further strengthened by the use of detailed records of daily respiratory symptoms and use of asthma medication, available on more than 99% of study days. Future studies incorporating indoor pollen exposures and activity patterns would be beneficial to further investigate the association between pollen exposures and asthmatic symptoms.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Table 1

Allergen, Weather and Criteria Pollutant Levels Averaged Across the Study Region

			Percentile			
	Mean (SD)	**Minimum**	**25th**	**50th**	**75^{th}**	**Maximum**
Total Pollen (grains/m^3)	473.6 (502.2)	0.0	69.2	318.9	750.9	4187.0
Tree Pollen (grains/m^3)	40.9 (76.2)	0.0	6.1	20.3	46.4	1034.0
Grass Pollen (grains/m^3)	12.8 (13.3)	0.0	2.5	6.9	20.5	63.0
Weed Pollen (grains/m^3)	37.1 (38.5)	0.0	8.4	20.8	56.6	222.0
Maximum Temperature (°C)	23.8 (6.2)	2.8	20.0	25.5	28.3	37.2
Maximum 8-hr O_3 (ppm)	0.06 (0.02)	0.01	0.05	0.06	0.07	0.17
$PM_{2.5}$ (μg/m^3)	14.1 (9.3)	0.0	7.6	11.8	17.7	45.6
NO_2 (ppb)	0.02 (0.01)	0.00	0.01	0.02	0.02	0.05
SO_2 (ppm)	0.003 (0.002)	0.000	0.001	0.002	0.004	0.019

Table 2

Demographic Characteristics Stratified by Use of Asthma Maintenance Medication

Variable	Users (n=258) No. (%)	Nonusers (n=172) No. (%)
Sex		
Boys	171 (66)	100 (58)
Girls	87 (34)	72 (42)
Age (years)		
4 to <8	114 (44)	77 (45)
8-12	144 (56)	95 (55)
Ethnicity		
White	183 (71)	100 (58)
Hispanic	36 (14)	37 (22)
Black	29 (11)	29 (17)
Asian/other	10 (4)	6 (4)
Maternal Education		
<High School	20 (8)	11 (6)
High School and Some College	129 (50)	97 (56)
College Degree	107 (425)	64 (37)
No Response	2 (1)	0 (0)
Exposed to Smoking		
No	240 (93)	162 (94)
Yes	18 (7)	10 (6)
Allergen Sensitization (IgE>0.35kU/L)*		
Grass Allergen	53 (27)	30 (24)
Ragweed Allergen	48 (25)	22 (18)

*Serum IgE collected for 319 participants (195 maintenance medication users, 124 non-users)

Table 3

Percent of Days with Symptoms and Rescue Medication Use by Pollen Season and Maintenance Medication Use Status

	Maintenance Medication			
	Users (n=258)		Non-users (n=172)	
	Median (IQR)	**Range**	**Median (IQR)**	**Range**
Within Pollen Season				
Any Symptom	4.9 (7.5)	0-78.0	0.90 (4.5)	0-61.2
Wheeze	1.8 (5.4)	0-34.5	0.0 (1.2)	0-28.3
Night Symptoms	1.8 (4.8)	0-67.3	0.0 (1.9)	0-28.2
Shortness of Breath	0.6 (4.0)	0-28.5	0.0 (0.7)	0-24.1
Chest Tightness	1.2 (3.9)	0-25.9	0.0 (0.6)	0-20.0
Persistent Cough	2.6 (7.0)	0-71.4	0.0 (3.1)	0-53.5
Rescue Medication Use	5.7 (18.3)	0-100	0.0 (1.8)	0-70.3
Outside Pollen Season				
Any Symptom	9.5 (13.7)	0-92.4	6.0 (6.4)	0-85.6
Wheeze	3.8 (8.5)	0-68.9	0.0 (2.9)	0-25.6
Night Symptoms	3.6 (8.6)	0-92.4	1.5 (3.9)	0-81.8
Shortness of Breath	2.5 (5.2)	0-45.0	0.0 (2.0)	0-18.2
Chest Tightness	2.4 (5.9)	0-46.9	0.0 (1.9)	0-22.6
Persistent Cough	6.8 (11.8)	0-92.4	2.1 (5.6)	0-84.4
Rescue Medication Use	10.0 (25.1)	0-100	1.0 (3.9)	0-100.0

Table 4

Association of Pollens and Same-Day Asthmatic Symptoms and Rescue Medication Use[a] by Use of Asthma Maintenance Medication

Pollen (grains/m^3)	Any Symptom OR (95% CI)	Symptoms: Wheeze OR (95% CI)	Symptoms: Night Symptoms OR (95% CI)	Symptoms: Shortness of Breath OR (95% CI)	Symptoms: Chest Tightness OR (95% CI)	Symptoms: Persistent Cough OR (95% CI)	Rescue Medication Use
Users of Asthma Maintenance Medication							
Total Pollen							
>1519	1.05 (0.85-1.29)	1.05 (0.77-1.44)	1.20 (0.93-1.54)	1.09 (0.79-1.51)	1.03 (0.76-1.41)	1.01 (0.82-1.24)	0.96 (0.87-1.05)
348-1519	1.00 (0.83-1.21)	1.00 (0.76-1.32)	1.07 (0.86-1.32)	1.09 (0.78-1.52)	0.87 (0.64-1.20)	0.95 (0.78-1.15)	0.98 (0.90-1.05)
61-347	0.97 (0.83-1.13)	0.97 (0.78-1.21)	1.00 (0.84-1.18)	1.07 (0.79-1.44)	0.94 (0.73-1.22)	0.93 (0.79-1.09)	0.96 (0.90-1.03)
10-60	0.96 (0.85-1.08)	0.92 (0.76-1.12)	1.00 (0.87-1.14)	0.99 (0.78-1.27)	0.92 (0.74-1.14)	0.89 (0.78-1.02)	0.96 (0.91-1.01)
0-9[b]	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Tree Pollen							
>379	1.06 (0.90-1.24)	1.15 (0.92-1.42)	1.07 (0.88-1.30)	1.23 (0.96-1.57)	1.10 (0.87-1.39)	1.01 (0.88-1.17)	1.00 (0.92-1.08)
92-379	1.02 (0.90-1.16)	1.19 (1.01-1.41)	1.04 (0.87-1.25)	1.37 (1.09-1.71)	1.13 (0.93-1.38)	0.97 (0.84-1.12)	1.00 (0.94-1.08)
17-91	1.04 (0.93-1.18)	1.13 (0.97-1.32)	1.04 (0.90-1.19)	1.31 (1.07-1.61)	1.06 (0.85-1.31)	0.97 (0.86-1.10)	0.99 (0.92-1.06)
9-16	1.03 (0.92-1.15)	1.01 (0.86-1.18)	1.05 (0.89-1.22)	0.96 (0.77-1.21)	1.02 (0.83-1.25)	1.03 (0.91-1.17)	1.02 (0.96-1.08)
0-8[b]	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Grass Pollen							
>15	1.00 (0.82-1.22)	0.94 (0.69-1.27)	1.15 (0.92-1.43)	0.88 (0.63-1.23)	0.93 (0.67-1.28)	1.00 (0.83-1.21)	1.02 (0.93-1.10)
9-15	0.99 (0.83-1.17)	0.93 (0.74-1.17)	1.11 (0.92-1.34)	0.99 (0.75-1.29)	0.93 (0.70-1.23)	1.01 (0.86-1.18)	1.00 (0.92-1.08)
5-8	1.02 (0.88-1.17)	1.01 (0.82-1.24)	1.02 (0.86-1.22)	1.07 (0.84-1.36)	0.97 (0.76-1.24)	0.96 (0.84-1.09)	1.01 (0.94-1.08)
3-4	0.96 (0.85-1.07)	0.91 (0.76-1.09)	0.95 (0.83-1.09)	0.92 (0.74-1.15)	0.90 (0.71-1.13)	0.99 (0.90-1.10)	0.99 (0.93-1.06)
0-2[b]	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Weed Pollen							
>51	1.23 (1.01-1.50)	1.18 (0.89-1.57)	1.20 (0.91-1.57)	1.34 (0.97-1.85)	1.30 (0.88-1.93)	1.05 (0.85-1.28)	1.11 (1.02-1.21)
25-51	1.24 (1.01-1.52)	1.30 (0.97-1.73)	1.21 (0.96-1.52)	1.43 (1.01-2.01)	1.30 (0.90-1.87)	1.06 (0.88-1.28)	1.14 (1.05-1.24)
10-24	1.18 (1.00-1.40)	1.26 (1.00-1.59)	0.99 (0.79-1.25)	1.48 (1.11-1.98)	1.28 (0.98-1.68)	1.15 (0.96-1.37)	1.09 (1.02-1.17)
6-9	1.10 (0.96-1.25)	1.22 (0.98-1.51)	1.09 (0.95-1.25)	1.37 (1.08-1.74)	1.16 (0.93-1.45)	1.11 (0.98-1.27)	1.06 (1.00-1.12)
0-5[b]	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Pollen (grains/m^3)	Symptoms						
	Any Symptom OR (95% CI)	Wheeze OR (95% CI)	Night Symptoms OR (95% CI)	Shortness of Breath OR (95% CI)	Chest Tightness OR (95% CI)	Persistent Cough OR (95% CI)	Rescue Medication Use
Non-users of Asthma Maintenance Medication							
Total Pollen							
>1519	1.10 (0.79-1.53)	1.13 (0.61-2.09)	0.98 (0.64-1.50)	1.04 (0.55-1.96)	1.04 (0.49-2.22)	1.04 (0.75-1.43)	1.06 (0.67-1.67)
348-1519	1.04 (0.80-1.36)	1.08 (0.67-1.74)	1.08 (0.73-1.61)	0.93 (0.55-1.58)	0.83 (0.44-1.59)	1.01 (0.74-1.37)	0.99 (0.71-1.37)
61-347	1.03 (0.80-1.32)	1.04 (0.67-1.63)	1.15 (0.83-1.59)	0.93 (0.58-1.49)	0.88 (0.51-1.52)	1.06 (0.81-1.38)	0.99 (0.75-1.30)
10-60	1.11 (0.91-1.36)	1.16 (0.84-1.62)	1.09 (0.80-1.48)	1.08 (0.71-1.64)	1.28 (0.81-2.02)	1.12 (0.89-1.42)	1.06 (0.84-1.33)
0-9[b]	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Tree Pollen							
>379	0.95 (0.75-1.21)	0.98 (0.60-1.60)	0.95 (0.66-1.37)	1.21 (0.71-2.05)	1.19 (0.53-2.68)	1.00 (0.76-1.30)	0.89 (0.68-1.16)
92-379	1.00 (0.79-1.27)	1.21 (0.79-1.86)	1.10 (0.83-1.46)	1.05 (0.56-1.95)	1.12 (0.53-2.38)	0.95 (0.76-1.18)	0.89 (0.68-1.16)
17-91	0.93 (0.73-1.18)	1.12 (0.73-1.72)	0.83 (0.61-1.13)	1.14 (0.68-1.90)	0.75 (0.40-1.43)	0.90 (0.71-1.14)	0.91 (0.72-1.14)
9-16	0.94 (0.75-1.18)	1.03 (0.73-1.45)	0.97 (0.69-1.35)	1.07 (0.69-1.65)	1.18 (0.67-2.09)	0.96 (0.76-1.22)	1.00 (0.78-1.27)
0-8[b]	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Grass Pollen							
>15	1.48 (0.98-2.23)	1.00 (0.54-1.85)	2.29 (1.22-4.29)	1.42 (0.67-2.99)	0.92 (0.44-1.90)	1.70 (1.21-2.38)	1.21 (0.75-1.96)
9-15	1.34 (0.91-1.98)	0.96 (0.54-1.70)	2.02 (1.07-3.80)	1.22 (0.58-2.59)	0.81 (0.39-1.68)	1.60 (1.15-2.21)	0.96 (0.61-1.52)
5-8	1.37 (0.94-2.01)	1.12 (0.65-1.94)	2.03 (1.18-3.49)	1.17 (0.55-2.48)	0.80 (0.39-1.64)	1.59 (1.19-2.12)	1.08 (0.71-1.65)
3-4	1.20 (0.84-1.73)	0.96 (0.58-1.58)	1.69 (1.08-2.64)	1.12 (0.53-2.38)	0.82 (0.43-1.58)	1.42 (1.14-1.77)	0.99 (0.67-1.45)
0-2[b]	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Weed Pollen							
>51	1.30 (0.94-1.79)	1.40 (0.79-2.49)	1.52 (0.96-2.40)	1.17 (0.58-2.38)	1.02 (0.49-2.11)	1.13 (0.83-1.53)	1.43 (0.91-2.24)
25-51	1.16 (0.88-1.52)	1.55 (1.00-2.39)	1.04 (0.73-1.49)	1.69 (0.93-3.09)	1.60 (0.90-2.86)	0.99 (0.76-1.28)	1.35 (0.90-2.02)
10-24	0.99 (0.75-1.31)	1.25 (0.82-1.91)	0.87 (0.58-1.30)	1.36 (0.85-2.19)	1.10 (0.73-1.64)	0.97 (0.78-1.21)	1.03 (0.69-1.54)
6-9	1.11 (0.90-1.38)	1.35 (0.95-1.92)	1.06 (0.83-1.34)	1.39 (0.87-2.23)	1.03 (0.70-1.52)	0.89 (0.71-1.12)	1.43 (1.05-1.96)
0-5[b]	1.00	1.00	1.00	1.00	1.00	1.00	1.00

[a] models were adjusted for maximum daily temperature, maximum 8-hr O_3, $PM_{2.5}$, antibiotic use and season

[b] Reference category

Table 5

Association of Pollens and Same-Day Asthmatic Symptoms and Rescue Medication Use by Sensitization Status[a] and Use of Asthma Maintenance Medication

Pollen (grains/m^3)	Symptoms						Rescue Medication Use
	Any Symptom OR (95% CI)	Wheeze OR (95% CI)	Night Symptoms OR (95% CI)	Shortness of Breath OR (95% CI)	Chest Tightness OR (95% CI)	Persistent Cough OR (95% CI)	
				Users of Asthma Maintenance Medication			
Grass: Not Sensitized							
>15	1.01 (0.80-1.27)	1.07 (0.71-1.60)	1.12 (0.89-1.41)	1.09 (0.74-1.62)	1.01 (0.67-1.52)	1.06 (0.85-1.31)	1.01 (0.92-1.11)
9-15	0.95 (0.76-1.18)	1.00 (0.76-1.33)	1.00 (0.81-1.25)	1.23 (0.88-1.71)	0.93 (0.63-1.38)	1.00 (0.82-1.22)	1.02 (0.93-1.11)
5-8	1.03 (0.86-1.23)	1.04 (0.81-1.34)	1.02 (0.85-1.23)	1.14 (0.84-1.54)	1.07 (0.79-1.46)	0.99 (0.85-1.15)	1.04 (0.98-1.12)
3-4	1.04 (0.92-1.17)	1.03 (0.86-1.25)	0.91 (0.80-1.04)	1.07 (0.84-1.38)	1.13 (0.91-1.40)	1.06 (0.94-1.20)	1.03 (0.97-1.10)
0-2[b]	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Grass: Sensitized							
>15	0.90 (0.57-1.42)	0.78 (0.41-1.48)	1.20 (0.78-1.86)	0.74 (0.39-1.40)	0.91 (0.45-1.83)	0.99 (0.65-1.52)	0.93 (0.78-1.11)
9-15	0.94 (0.63-1.40)	0.76 (0.43-1.33)	1.17 (0.83-1.65)	0.78 (0.44-1.36)	0.99 (0.58-1.70)	0.99 (0.70-1.42)	0.87 (0.71-1.05)
5-8	0.97 (0.67-1.40)	0.91 (0.56-1.47)	1.09 (0.77-1.55)	1.03 (0.63-1.71)	0.98 (0.58-1.66)	1.01 (0.73-1.39)	0.93 (0.75-1.15)
3-4	0.68 (0.49-0.94)	0.57 (0.39-0.83)	0.90 (0.59-1.37)	0.53 (0.35-0.82)	0.45 (0.26-0.79)	0.85 (0.67-1.07)	0.85 (0.70-1.04)
0-2[b]	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Weed: Not Sensitized							
>51	1.12 (0.88-1.42)	1.07 (0.72-1.58)	1.14(0.80-1.63)	1.02 (0.65-1.61)	1.07 (0.60-1.92)	0.93 (0.72-1.20)	1.07 (0.97-1.18)
25-51	1.10 (0.85-1.42)	1.08 (0.70-1.66)	1.06 (0.80-1.42)	1.04 (0.66-1.64)	1.01 (0.62-1.65)	1.01 (0.79-1.28)	1.09 (0.98-1.20)
10-24	1.03 (0.84-1.25)	1.18 (0.83-1.66)	0.90 (0.68-1.18)	1.19 (0.82-1.72)	1.07 (0.76-1.51)	1.06 (0.84-1.32)	1.07 (0.98-1.16)
6-9	1.07 (0.90-1.27)	1.29 (0.92-1.81)	1.07 (0.92-1.24)	1.22 (0.86-1.73)	1.06 (0.78-1.45)	1.10 (0.93-1.31)	1.03 (0.96-1.11)
0-5[b]	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Weed: Sensitized							
>51	1.78 (1.17-2.69)	1.82 (1.05-3.15)	1.35 (0.87-2.10)	2.52 (1.39-4.55)	2.23 (1.22-4.07)	1.35 (0.87-2.10)	1.15 (1.02-1.31)
25-51	1.84 (1.24-2.75)	2.38 (1.53-3.70)	1.54 (0.92-2.56)	2.48 (1.35-4.53)	2.49 (1.37-4.50)	1.30 (0.89-1.89)	1.22 (1.04-1.42)
10-24	1.94 (1.39-2.71)	2.00 (1.38-2.89)	1.32 (0.78-2.23)	2.38 (1.37-4.14)	2.04 (1.38-3.04)	1.57 (1.03-2.39)	1.19 (1.04-1.37)
6-9	1.31 (1.00-1.73)	1.35 (0.94-1.94)	1.35 (0.99-1.86)	1.76 (1.19-2.59)	1.63 (1.09-2.44)	1.18 (0.89-1.57)	1.12 (1.02-1.22)
0-5[b]	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Pollen (grains/m^3)	Symptoms						
	Any Symptom OR (95% CI)	**Wheeze OR (95% CI)**	**Night Symptoms OR (95% CI)**	**Shortness of Breath OR (95% CI)**	**Chest Tightness OR (95% CI)**	**Persistent Cough OR (95% CI)**	**Rescue Medication Use**
Non-users of Asthma Maintenance Medication							
Grass: Not Sensitized							
>15	1.24 (0.64-2.38)	0.70 (0.24-1.99)	1.44 (0.61-3.40)	0.95 (0.26-3.50)	0.44 (0.16-1.26)	1.99 (1.14-3.46)	0.93 (0.38-2.29)
9-15	1.03 (0.56-1.91)	0.76 (0.31-1.88)	1.49 (0.62-3.62)	0.57 (0.18-1.80)	0.28 (0.13-0.57)	1.79 (0.99-3.24)	0.68 (0.30-1.54)
5-8	1.09 (0.58-2.03)	0.84 (0.32-2.18)	1.45 (0.69-3.05)	0.82 (0.24-2.83)	0.39 (0.15-1.00)	1.65 (1.00-2.73)	0.88 (0.37-2.05)
3-4	0.89 (0.48-1.67)	0.61 (0.26-1.40)	1.05 (0.55-1.97)	0.81 (0.26-2.50)	0.47 (0.23-0.95)	1.28 (0.85-1.94)	0.54 (0.27-1.07)
0-2 (reference)	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Grass: Sensitized							
>15	2.64 (1.55-4.49)	2.54 (1.08-6.01)	3.67 (1.62-8.34)	3.39 (1.72-6.66)	1.64 (0.60-4.48)	1.86 (1.11-3.11)	2.12 (1.39-3.22)
9-15	2.58 (1.60-4.18)	2.04 (1.01-4.11)	3.99 (2.13-7.49)	3.39 (1.52-7.55)	3.01 (1.66-5.46)	1.70 (1.15-2.53)	1.82 (1.22-2.72)
5-8	2.09 (1.31-3.33)	2.16 (1.20-3.89)	3.26 (1.90-5.59)	2.06 (1.13-3.77)	1.90 (1.07-3.38)	1.62 (1.23-2.12)	1.66 (1.23-2.23)
3-4	1.80 (1.31-2.47)	1.82 (1.24-2.67)	2.56 (1.72-3.79)	2.18 (1.19-3.99)	1.88 (0.93-3.78)	1.71 (1.44-2.03)	1.41 (0.98-2.03)
0-2 (reference)	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Weed: Not Sensitized							
>51	1.28 (0.83-1.97)	1.33 (0.56-3.16)	1.18 (0.80-1.75)	1.66 (0.63-4.38)	1.61 (0.52-4.99)	1.01 (0.66-1.54)	1.51 (0.96-2.40)
25-51	1.10 (0.76-1.60)	1.40 (0.66-2.99)	0.90 (0.63-1.28)	1.80 (0.75-4.29)	1.79 (0.78-4.15)	0.88 (0.60-1.27)	1.60 (1.02-2.50)
10-24	0.84 (0.54-1.31)	0.84 (0.43-1.64)	0.72 (0.48-1.06)	1.09 (0.51-2.31)	1.19 (0.59-2.42)	0.84 (0.62-1.15)	1.09 (0.65-1.83)
6-9	1.21 (0.87-1.67)	1.84 (1.15-2.96)	1.09 (0.80-1.48)	1.52 (0.80-2.91)	1.47 (0.82-2.64)	0.76 (0.54-1.08)	1.79 (1.26-2.53)
0-5 (reference)	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Weed: Sensitized[c]							
>51	1.90 (0.91-3.96)					1.40 (0.58-3.36)	1.03 (0.24-4.48)
25-51	1.57 (0.89-2.78)					1.29 (0.76-2.17)	0.67 (0.22-1.99)
10-24	1.12 (0.62-2.02)					1.08 (0.57-2.08)	0.32 (0.08-1.23)
6-9	1.28 (1.02-1.60)					1.27 (0.94-1.70)	0.39 (0.13-1.14)
0-5 (reference)	1.00					1.00	1.00

[a] models were adjusted for maximum daily temperature, maximum 8-hr O_3, $PM_{2.5}$, antibiotic use and season

[b] Reference category

[c] sample size for maintenance medication users sensitized to weed pollen (n=22) was insufficient for analysis of less frequent outcomes