Association between climate factors, pollen counts, and childhood hay fever prevalence in the United States

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Background: Climate factors and pollen counts may play a role in hay fever.

Objective: We sought to determine the impact of specific climate factors and pollen counts on the US prevalence of hay fever and statewide variation in prevalence.

Methods: We used a merged analysis of the 2007 National Survey of Children's Health from a representative sample of 91,642 children aged 0 to 17 years and the 2006-2007 National Climate Data Center and Weather Service measurements of relative humidity (%), indoor heating degree days, precipitation, Palmer Hydrological Drought Index, clear sky and issued ultraviolet indices, stratospheric ozone levels, and outdoor air temperature and National Allergy Bureau total pollen counts. Multivariate survey logistic regression models controlled for sex, race/ethnicity, age, household income, and birthplace.

Results: The US prevalence of hay fever in childhood was 18.0% (95% CI, 17.7% to 18.2%), with the highest prevalence in southeastern and southern states. Hay fever prevalence was significantly lower with second and third quartile mean annual relative humidity (logistic regression, $P \leq .01$ for both), fourth quartile mean annual Palmer Hydrological Drought Index ($P = .02$), third and fourth quartile mean annual heating degree days ($P < .0001$ for both), and third and fourth quartile mean annual stratospheric ozone levels but increased with second, third, and fourth quartile mean annual temperature ($P \leq .02$ for both), fourth quartile mean annual precipitation ($P = .0007$), mean total pollen counts ($P = .01$), and second, third, and fourth quartile issued ultraviolet index ($P \leq .0001$ for all). Principal-component analysis was also used to determine the combined effects of correlated climate variables and pollen counts.

Conclusions: This study provides evidence of the influence of climate on the US prevalence of childhood hay fever. (J Allergy Clin Immunol 2015;135:463-9.)

Key words: *Hay fever prevalence, rhinoconjunctivitis, relative humidity, indoor heating, ultraviolet index, stratospheric ozone levels, air temperature, Palmer drought index, precipitation, rain, pollen count, pediatric, children*

Hay fever (HF) is a common disorder that can be a significant cause of morbidity. The lifetime prevalence of physician-diagnosed HF in the United States was 10.8%, with the majority diagnosed in childhood.[1] A recent population-based study demonstrated that the prevalence of HF and other atopic diseases is lower in foreign-born American children but increases with prolonged residence in the United States.[2] This suggests that regional differences in environmental factors may contribute toward these trends, including climate, allergen, and dietary exposures. However, no studies have examined the statewide variation in HF prevalence within the United States and its determinants.

Several studies have examined the role of climate in allergic disease. Silverberg et al[3] recently demonstrated significant associations between eczema prevalence in the United States and several climate factors, including lower humidity, temperature, and ultraviolet (UV) exposure; however, HF was not studied. Several international studies have examined the relationship between climate and HF. A study of 146 centers from the International Study of Asthma and Allergies found associations between HF prevalence and some long-term climate variables, including higher annual temperature and lower outdoor relative humidity.[4] However, these associations were not reproducible in all regions and age groups. A study of 5729 Australians found an association of HF with higher UV exposure.[5] In the present study, we examined the effects of climate variables and pollen counts on childhood HF prevalence in the United States.

METHODS

National Survey of Children's Health

We used data from the 2007 National Survey of Children's Health (NSCH) of 91,642 households (>1,700 subjects per state), which was designed to estimate the prevalence of various child health issues. The NSCH was sponsored by the Maternal and Child Health Bureau and the US Department of Health and Human Services. The telephone numbers were chosen at random, followed by identification of households with 1 or more children younger than 18 years. Subsequently, 1 child was randomly selected for interview. The survey results were weighted to represent the population of noninstitutionalized children nationally and in each state using data from the US Census Bureau, by adjusting for age, sex, race/ethnicity, household size, and educational attainment of the most educated household member. Verbal informed consent was obtained before interview. Approval for the study was obtained by the institutional review board at St Luke's-Roosevelt Hospital Center.

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Abbreviations used
HDD: Heating degree day
HF: Hay fever
NSCH: National Survey of Children's Health
OR: Odds ratio
PCA: Principal-component analysis
PHDI: Palmer Hydrological Drought Index
UV: Ultraviolet

Climate variables and pollen counts

Seasonal and annual statewide mean values of relative humidity (%) were downloaded from National Oceanic & Atmospheric Administration, National Climate Data Center, at http://www7.ncdc.noaa.gov/CDO/dataproduct. Relative humidity is a measure of water vapor in the air that is dependent on both the air temperature and pressure.

Monthly and annual statewide mean values of issued UV index and stratospheric ozone levels (parts per billion) were downloaded from the National Oceanic & Atmospheric Administration, National Weather Service, Climate Prediction Center, at ftp://ftp.cpc.ncep.noaa.gov/long/uv/cities. Issued UV index accounts for the effects of clouds on UV transmission. UV index exposure has been categorized by the World Health Organization as low (0-2), moderate (3-5), high (6-7), very high (8-10), and extreme (≥11). For more information about UV indices, please refer to http://www.cpc.ncep.noaa.gov/products/stratosphere/uv_index/uv_information.shtml. Because the stratospheric ozone layer filters all UVC and the majority of UVB radiation, we studied stratospheric ozone levels as a marker of UV exposure.

Monthly and annual statewide mean values of temperatures (°F to 10ths), heating degree days (HDDs) (whole number), and Palmer Hydrological Drought Index (PHDI) were downloaded from the National Oceanic & Atmospheric Administration, National Climate Data Center, at ftp://ftp.ncdc.noaa.gov/pub/data/cirs/. Temperatures were corrected for "time-bias" as per the method of Karl et al.[6] Time-bias correction adjusts the mean temperature values over a 24-hour period from each individual station to coincide with the calendar day. HDD is a statewide population-weighted measure of energy demand to heat indoor structures by 1°F for 1 day using a baseline temperature of 65°F. For example, a value of 3 would mean that the outdoor temperature that day would require buildings to use enough energy to heat their buildings by 3°F. The PHDI is a long-term measure of hydrological drought and wet conditions that reflects groundwater and reservoir levels. A lower score reflects dryer conditions, whereas a higher score reflects wetter conditions.

Daily total pollen counts were generously provided by the National Allergy Bureau. Pollen counts were available for 27 sites across 21 states and districts.

Prevalence of HF

Prevalence of HF was determined using the NSCH question, "During the past 12 months, have you been told by a doctor or other health professional that (child) had hay fever or any kind of respiratory allergy?" This is referred to as *hay fever* throughout the article.

Data processing and statistical methods

All data processing and statistical analyses were performed in SAS version 9.2 (SAS Institute, Cary, NC). The above-mentioned climate variables were limited to the period 2006 to 2007 and were merged by the state of residence. In scenarios in which there were climate observations for multiple cities within a state, the mean value of all the cities was used. Mean annual values for variables were used for statistical modeling. All the climate variables had highly skewed and multimodal distributions, which precluded their being analyzed as a continuous variable. Variables were therefore divided into quartiles, with the lowest quartile as the referent group.

Univariate and multivariate associations were tested by using survey logistic regression (PROC SURVEYLOGISTIC). The dependent binary variable was HF, and the independent variables included the above-mentioned climate factors and pollen counts tested individually in univariate models. Age, sex, race/ethnicity, and household income were included in multivariate models because of significant confounding and/or effect modification. Complete data analysis was performed; that is, subjects with missing data were excluded. Linear interaction terms between age, sex, race/ethnicity, and household income were tested and included in the final models if significant ($P < .05$). All population estimates were determined using the predefined sampling weights for the NSCH.

Relative humidity, the UV index, temperature, HDD, PHDI, and pollen counts were highly correlated. Therefore, principal-component analysis (PCA) with varimax rotation was used to estimate the combined effects of these climate variables.[7] PCA was used to determine the best combination and weighting of climate variables to best explain how they are correlated. Factors were retained if the eigenvalue was more than 1, the proportion of variance accounted for more than 10%, and the loading value was more than 0.4. Retained factors represent the dominant combinations of these climate variables occurring in the United States. Logistic regression was performed using factor scores from the retained factors to determine the odds of HF under these common climate conditions.

Correction for multiple dependent tests (k = 89) was performed by minimizing the false-discovery rate with the approach of Benjamini and Hochberg[8] and yielded a critical *P* value of .020.

RESULTS

Population characteristics

Overall, the prevalence of HF was 18.0% (95% CI, 17.7-18.2). The prevalence of HF was higher in older children, boys, and households with higher income but lower in Hispanics compared with whites and those born outside the United States (Table I).

Statewide variation in the prevalence of HF

There was a significant statewide variation in the prevalence of HF, with the highest prevalence of HF in the southeastern and southern states ($P < .0001$) (Fig 1, *A*). The states with the lowest prevalence [95% CI] of HF were Minnesota (10.0% [8.1% to 11.9%]), Vermont (10.4% [8.5% to 12.4%]), and Alaska (10.5% [8.5% to 12.5%]).

Relative humidity

The highest mean annual relative humidity occurred predominantly in coastal states (Fig 1, *B*). Residence in a state with the second quartile (16.5%; logistic regression, adjusted odds ratio [OR] [95% CI], *P*, 0.90 [0.82-0.98], .01) and third quartile (16.8%; 0.89 [0.81-0.97], .008) mean annual relative humidity was associated with decreased prevalence of HF compared with that in a state with the lowest quartile (17.7%) (Table II). However, the fourth-quartile humidity was not significantly associated with the prevalence of HF in multivariate models ($P = .22$).

Drought index

The highest mean annual PHDI, that is, wetter conditions, occurred predominantly in southeastern and southwestern states (Fig 1, *C*). Residence in a state with the highest quartile mean annual PHDI was associated with decreased prevalence of HF compared with that in a state with the lowest quartile (16.8% vs 18.2%; 0.89 [0.81-0.98], $P = .02$) (Table II). However, second- and third-quartile drought index was not associated with HF prevalence ($P \geq .08$). HF prevalence varied by the seasonal drought index, where the third- and fourth-quartile mean PHDI values were significantly associated with lower HF prevalence in winter and