Original Article

Exposure to Extreme Heat Events Is Associated with Increased Hay Fever Prevalence among Nationally Representative Sample of US Adults: 1997-2013

Crystal Romeo Upperman, PhD[a,b], Jennifer D. Parker, PhD[c], Lara J. Akinbami, MD[c], Chengsheng Jiang, PhD[a], Xin He, PhD[d], Raghuram Murtugudde, PhD[e], Frank C. Curriero, PhD[f], Lewis Ziska, PhD[g], and Amir Sapkota, PhD[a]
College Park, Hyattsville, Baltimore, and Beltsville, Md

What is already known about this topic? Extreme heat events are projected to increase in frequency, duration, and intensity in coming decades in response to changing climate.

What does this article add to our knowledge? We show that exposure to extreme heat event is associated with increased hay fever prevalence among US adults.

How does this study impact current management guidelines? Future clinical guidance on allergen avoidance and medication initiation may need to consider frequency and timing of extreme heat events.

BACKGROUND: Warmer temperature can alter seasonality of pollen as well as pollen concentration, and may impact allergic diseases such as hay fever. Recent studies suggest that extreme heat events will likely increase in frequency, intensity, and duration in coming decades in response to changing climate.

OBJECTIVE: The overall objective of this study was to investigate if extreme heat events are associated with hay fever.
METHODS: We linked National Health Interview Survey (NHIS) data from 1997 to 2013 (n = 505,386 respondents) with extreme heat event data, defined as days when daily maximum temperature (TMAX) exceeded the 95th percentile values of TMAX for a 30-year reference period (1960-1989). We used logistic regression to investigate the associations between exposure to annual and seasonal *extreme heat events* and adult hay fever prevalence among the NHIS respondents.
RESULTS: During 1997-2013, hay fever prevalence among adults 18 years and older was 8.43%. Age, race/ethnicity, poverty status, education, and sex were significantly associated with hay fever status. We observed that adults in the highest quartile of exposure to extreme heat events had a 7% increased odds of hay fever compared with those in the lowest quartile of exposure (odds ratios: 1.07, 95% confidence interval: 1.02-1.11). This relationship was more pronounced for extreme heat events that occurred during spring season, with evidence of an exposure-response relationship (P_{trend} < .01).
CONCLUSIONS: Our data suggest that exposure to extreme heat events is associated with increased prevalence of hay fever among US adults. © 2016 American Academy of Allergy, Asthma & Immunology (J Allergy Clin Immunol Pract 2016;■:■-■)

Key words: *Allergy; Allergic rhinitis; Climate change; Extreme heat events; Extreme weather events; Hay fever*

Hay fever affects 17.6 million (7.5%) adults in the United States annually and can have an impact on their quality of life.[1-3] In 2005, hay fever-related medical expenses in the United States amounted to $11.2 billion.[4,5]

[a]Maryland Institute for Applied Environmental Health, School of Public Health, University of Maryland, College Park, Md
[b]Marine Estuarine Environmental Science Program, College of Computer Mathematics and Natural Sciences, University of Maryland, College Park, Md
[c]National Center for Health Statistics, Centers for Disease Control and Prevention, Hyattsville, Md
[d]Department of Epidemiology and Biostatistics, School of Public Health, University of Maryland, College Park, Md
[e]Department of Atmospheric and Oceanic Science, University of Maryland, College Park, Md
[f]Department of Epidemiology and Biostatistics, Bloomberg School of Public Health, Johns Hopkins University, Baltimore, Md
[g]Crop Systems and Global Change Laboratory, Agricultural Research Service, United States Department of Agriculture, Beltsville, Md
This study was funded by National Institute of Environmental Health Sciences (NIEHS) grant 1R21ES021422-01A1 to C.J., F.C.C., and A.S. This publication was also made possible by U.S. Environmental Protection Agency (EPA) Science To Achieve Results (STAR) grant (F13B20312) to C.R.U. Its contents are solely the responsibility of the grantee and do not necessarily represent the official views of the U.S. EPA. Further, the U.S. EPA does not endorse the purchase of any commercial products or services mentioned in the publication.
Conflicts of interest: The authors declare that they have no relevant conflicts.
Received for publication April 29, 2016; revised August 9, 2016; accepted for publication September 8, 2016.
Available online ■■
Corresponding author: Amir Sapkota, PhD, Maryland Institute for Applied Environmental Health, University of Maryland School of Public Health, 2234F, School of Public Health, Building #255, College Park, MD 20742. E-mail: amirsap@umd.edu.
2213-2198

http://dx.doi.org/10.1016/j.jaip.2016.09.016

Abbreviations used
- *CI- Confidence interval*
- *DSI-3200- Data set 3200*
- *EHE- Extreme heat events*
- *ETT_{95}- Extreme temperature threshold 95th percentile*
- *GED- General education development*
- *GHCN- Global Historical Climatology Network*
- *MSA- Metropolitan statistical area*
- *NCHS- National Center for Health Statistics*
- *NHIS- National Health Interview Survey*
- *OR- Odds ratio*
- *TMAX- Daily maximum temperature*

Hay fever, a term often used for seasonal allergic rhinitis, is a chronic condition caused by an inflammatory response to seasonal allergens, and is characterized by nasal congestion, clear rhinorrhea (runny nose), sneezing, and itching.[6-10] Hay fever is frequently underrecognized, misdiagnosed, and ineffectively treated.[11] The causes and triggers of hay fever are seasonal exposure to mold or trees, grass, and weed pollens.[6-10] Previous studies have linked a rise in ambient temperature with increases in respiratory diseases,[12-16] but no studies to date have investigated the role of extreme heat events on respiratory outcomes such as hay fever on a national scale.

An increasing body of literature suggests that the frequency, intensity, and duration of extreme weather events will continue to rise in the near future in response to changing climate.[17-19] The potential impact of these increases on allergic diseases is a growing concern that has not been empirically assessed for the contiguous United States. Prior studies have shown that increases in temperature and CO_2 concentrations affect plant phenology as well as concentration, distribution, and allergenicity of pollen.[20-22] This dynamic may worsen the burden of hay fever by increasing both the pollen season length and the potency of pollen.[22-24] An increased burden may differentially impact people living in urban versus rural areas, and those of low socioeconomic status, children, and older adults,[18] because of the urban heat island effect,[25] poor housing conditions,[26] and limited adaptive responses.[27]

Using 17 years of health outcome data (National Health Interview Survey [NHIS] 1997-2013; n = 505,386 respondents), we explored the association between exposures to increased frequency of extreme heat events and hay fever among a nationally representative sample of the adult civilian noninstitutionalized US population aged 18 years and older.

METHODS

Meteorological data

Daily weather data were obtained from 2 systems within the National Centers for Environmental Information—formerly known as the National Climatic Data Center—for the 1960-2013 period.[28] Data for the years 1960-2010 were extracted from the DSI-3200 data set. The DSI-3200 data set was discontinued in 2010 and replaced with the Global Historical Climatology Network (GHCN) data set that consists of additional stations that are not part of the original DSI-3200 network. Therefore, for the 2011-2013 period, we identified the DSI3200 stations within the GHCN using unique station identification and extracted information from this subset of stations to maintain consistency.

Exposure metric

Using daily maximum temperature (TMAX) for the 1960-1989 reference period, county-specific 30-year baselines for each calendar month were computed. On the basis of the distribution of these data, we identified the 95th percentile values of TMAX, referred to as Extreme Temperature Threshold 95th percentile (ETT_{95}) as previously described.[29] Daily TMAX values for each county were compared with their respective calendar-month-specific ETT_{95} and assigned a value of "1" if they exceeded the thresholds, and "0" otherwise. The ETT_{95} exceedances—referred to as *extreme heat events* (*EHE_{95}*)—were summed over each calendar month for each county during the 1997-2013 period for which NHIS hay fever prevalence data were available.

Extreme heat event values were assigned to individual NHIS records for each survey year in 2 ways: (1) the cumulative number of *extreme heat events* for the county of residence in a 12-month window, which include the month of interview and the preceding 11 months, and (2) the cumulative number of *extreme heat events* for the county of residence in each of the 4 complete seasons over the 12-month window preceding the month of interview. Seasons were categorized as follows: winter—December, January, February; spring—March, April, May; summer—June, July, August; fall—September, October, November.

NHIS, 1997-2013 data

We combined NHIS data for 1997-2013 for this analysis. The NHIS is a nationally representative cross-sectional household interview survey of the civilian noninstitutionalized population of the United States that has been conducted since 1957, although the survey design and questionnaire have changed over time.[30] The NHIS is conducted continuously throughout the year. Between 1997 and 2013, approximately 40,000 households were sampled each year, with some households having multiple families. In each family, a sample adult is selected for detailed questions on health and health care.[30] During the 17-year period, the sample adult response rates ranged from 60.8% to 80.4%.

We used the restricted-use NHIS files geocoded to county Federal Information Processing Standard. These files are available through the National Center for Health Statistics (NCHS) Research Data Center. There are 516,140 sample adults 18 years of age or older in the 1997-2013 NHIS. Respondents were excluded from the analysis if they: (1) resided in a county that had less than 12 months of extreme heat data and had at least one nonvalid month for the development of the baseline (n = 1185); (2) resided outside the 48 contiguous states at the time of the interview (n = 5334); or (3) had missing data for any of the variables used in the analysis (n = 4235), for a total of 10,754 (2%) excluded respondents.

Hay fever was identified using responses to the question: "During the past 12 months, have you been told by a doctor or other health professional that you had hay fever?" Demographic characteristics considered included age (18-34, 35-49, 50-64, 65+ years), race/ethnicity (Hispanic, non-Hispanic black, non-Hispanic white, all other races and ethnicities), sex (female, male), education level (less than high school/general education development [GED], high school/GED, some college, Bachelor degree, Graduate degree), and family income relative to poverty threshold (less than 100%, 100% to less than 200%, 200% to less than 400%, 400% or above the poverty threshold).[31,32] We used the NHIS multiple-imputed income data to assign poverty status level to records with missing values (percent missing ranged from 4.5% to 10.0% over 1997-2013) using NCHS-recommended methods.[33]

We also included a county-level geographical covariate describing urban-rural classification with 4 urban and 2 rural categories (urban: large central, large fringe, medium, and small metro; rural: micropolitan and noncore).[34] Large central metro counties are counties in Metropolitan Statistical Areas (MSAs) of 1 million or more population that contain the largest principal city of the MSA, are contained within the MSA's largest principal city, or contain at least 250,000 residents of any principal city. Large fringe metro counties are counties in MSAs of 1 million or more population that do not qualify as large central metro. They are considered to be "suburbs" of large cities. Medium and small metro counties are counties in MSAs of 250,000-999,999 and less than 250,000 population, respectively. Micropolitan and noncore counties are nonmetropolitan counties that are not in MSAs.

Statistical analysis

Associations between annual and seasonal total *extreme heat events* and adult hay fever were evaluated using logistic regression models in SUDAAN, which accounts for the complex clustered sample design of the NHIS.[35] Unadjusted and adjusted models were fitted separately for each overall annual cumulative lag and seasonal cumulative lag of *extreme heat events*. We fitted additional models for *seasonal extreme heat events* separately based on interview season defined in the description of the survey. The quartiles for overall exposure and seasonal exposure were based on the distribution of extreme heat events for all 3109 counties in the contiguous United States. Because the actual cutoff point for seasonal quartiles varied by season, we decided to use the same approximate cutoff for all seasons to maintain comparability.

RESULTS

Among adults aged 18 years and older, 8.43% (n = 42,601) reported being told that they had hay fever within the previous 12 months for the period 1997-2013 (Table I). All characteristics shown in Table I, except urban-rural classification, were significantly associated with hay fever status. After full adjustment, women have a 30% (odds ratio [OR]: 1.30, 95% confidence interval [CI]: 1.27-1.33) increased odds of being diagnosed with hay fever compared with men. Compared with Hispanics, non-Hispanic whites and non-Hispanic blacks have a 44% (OR: 1.44, 95% CI: 1.37-1.33) and a 9% (OR: 1.09, 95% CI: 1.03-1.15) increased odds of receiving a hay fever diagnosis. Likewise, compared with 18-34 year olds, those in 35-49, 50-64, and ≥65 year age groups had a 67%, 59%, and 13% increased odds of receiving a hay fever diagnosis, respectively. Also, as education and income increase, the odds of hay fever diagnosis also increases.

Extreme heat events (approximate quartiles of the cumulative number of *extreme heat events* in the 12 months preceding the survey) were significantly associated with hay fever prevalence in an unadjusted analysis (Table II, model 1). When adjusting for demographic characteristics (Table II, model 2), the association between extreme heat events and hay fever persisted, that is, compared with adults in the lowest quartile of exposure to extreme heat events (0-10 events), adults in the higher quartiles of exposures had higher odds of reporting a diagnosis of hay fever in the previous 12 months. This increase in odds ranged from 5% (OR: 1.05, 95% CI: 1.01-1.09) for adults in the second quartile to 7% (OR: 1.07, 95% CI: 1.03-1.11) for adults in the fourth quartile. Additional adjustment for urbanicity did not change the observed association (Table II, model 3).

When we analyzed by timing (season) of extreme heat events, we observed a clear exposure-response relationship for associations between springtime extreme heat events and odds of hay fever ($P_{trend} < .01$, Table III). For springtime extreme heat events, the increases in odds of hay fever ranged from 2% (OR: 1.02, 95% CI: 0.98-1.06) for adults in the second quartile to 7% (OR: 1.07, 95% CI: 1.03-1.12) for adults in the fourth quartile (Table III). For extreme heat events that occurred during summer and winter, the increases in the odds of hay fever were significant only among those in the highest quartile of exposure (Table III). Such associations were not observed for extreme heat events that occurred during fall.

Sensitivity analyses using both more liberal (90th percentile threshold) and more conservative (99th percentiles threshold) exposure metrics did not alter our overall findings related to extreme heat events and hay fever prevalence (Tables E1 and E2, available in this article's Online Repository at www.jaci-inpractice.org). Additional sensitivity analysis looking at the seasonal differences also showed more pronounced and consistent effect associated with springtime extreme heat events (Table E3, available in this article's Online Repository at www.jaci-inpractice.org). The effects of extreme heat events remained significantly associated with hay fever prevalence when all models were additionally adjusted for the month or year of interview (data not shown).

DISCUSSION

We evaluated the relationship between exposures to annual and seasonal extreme heat events and the prevalence of hay fever among a nationally representative sample of civilian noninstitutionalized US adults using NHIS data collected between 1997 and 2013. This analysis builds on previous work that has shown an association between increasing temperature and longer pollen seasons for important allergens such as ragweed.[22,23,36]

The present study found a modest positive association between exposures to extreme heat events, particularly during spring, and the prevalence of hay fever. For the extreme heat events during summer and fall, findings were significant only among individuals in the highest quartile of exposure. Our findings regarding exposures to extreme heat events and hay fever prevalence were not substantially affected by the adjustment for demographic factors and county urbanicity. The magnitude of the association, although small, has implications on a population level. That is, although individual clinicians may not observe dramatic increases in the number of affected patients, the US burden of hay fever could be significantly affected by an increase in extreme heat events. Although the exact mechanisms by which long-term exposures to extreme heat events increase the risk of hay fever remain unclear, one potential explanation is changes in plant phenology. Higher frequency of extreme heat events, particularly those occurring in winter and spring season, may lead to earlier onset of greening and flowering of plants including trees that are major sources of pollen.[22,23] This is supported by a more recent study that showed that the spring flowering taxa encountered the most pronounced increasing trend for pollen production compared with other season.[37] Earlier onset of spring effectively increases the duration of exposure to pollen, which is an important risk factor for hay fever.[21-23] Others have shown higher pollen production associated with warmer

TABLE I. Characteristics of adults 18 years and older*, NHIS 1997-2013

Variables	Categories	All (n = 505,386)	Hay fever (n = 42,601)	EHE$_{95}$ quartiles† 0-10 d (n = 111,524)	11-16 d (n = 113,255)	17-24 d (n = 123,998)	25 d or more (n = 156,609)
Total percent		100	8.43	21.91	22.49	24.65	30.94
Hay fever							
	No	91.57	—	21.99	22.47	24.66	30.88
	Yes	8.43	—	21.05	22.72	24.61	31.61
Race/ethnicity							
	Non-Hispanic white	71.28	9.20	22.46	23.07	24.33	30.14
	Non-Hispanic black	11.50	6.78	22.55	20.99	24.81	31.66
	Hispanic	12.52	5.73	18.98	20.65	25.81	34.56
	All other races and ethnicities	4.70	8.05	19.78	22.33	26.17	31.71
Sex							
	Male	48.13	7.45	21.89	22.54	24.77	30.80
	Female	51.87	9.35	21.93	22.45	24.55	31.08
Age							
	18-34 y	31.27	6.21	21.69	22.58	25.04	30.69
	35-49 y	29.40	10.34	21.86	22.50	24.76	30.88
	50-64 y	22.86	10.07	21.66	22.59	24.31	31.43
	65 y and older	16.48	6.98	22.78	22.16	24.21	30.85
Education							
	<High school/GED	16.24	6.00	21.92	22.12	25.19	30.77
	High school/GED	28.65	6.89	22.65	22.52	24.47	30.36
	Some college	29.48	9.19	22.11	22.57	24.55	30.78
	Bachelor degree	16.83	10.29	21.11	22.56	24.59	31.74
	Graduate degree	8.79	11.88	20.36	22.7	24.75	32.19
Poverty status‡							
	Less than 100%	12.33	6.92	21.99	21.92	24.88	31.22
	100 to less than 200%	18.40	6.96	22.79	21.91	24.70	30.60
	200 to less than 400%	31.17	7.99	22.55	22.48	24.51	30.46
	400% or greater	38.09	10.00	20.94	22.97	24.67	31.42
Urban-rural classification§							
	Large central metro	28.22	8.09	17.93	22.68	27.43	31.97
	Large fringe metro	24.00	9.08	23.10	22.94	23.39	30.57
	Medium metro	20.99	8.63	22.27	21.85	23.37	32.51
	Small metro	10.13	8.56	23.00	23.26	24.63	29.12
	Micropolitan	10.20	7.86	25.52	20.43	23.83	30.22
	Noncore	6.46	7.55	26.34	24.14	22.76	26.75

EHE$_{95}$, Extreme heat events—days where the daily maximum temperature value exceeded the county and calendar month specific 95th percentile threshold, calculated using 30 years of baseline data; *GED*, general education development; *NHIS*, National Health Interview Survey.
All percentages were weighted using NHIS survey weights.
*Includes sample adults 18 years and older with complete data for analytic covariates.
†The categories of days represent the quartiles of exposure based on county of residence.
‡Family income as a percent of poverty threshold.
§Counties were classified into urbanization levels based on the 2006 National Center for Health Statistics Urban-Rural Classification Scheme for Counties.

temperatures.[38,39] Increased frequency of extreme heat events may lead to higher concentration of pollen in the environment—in addition to increasing the possible duration of exposure.[16,38,40] Our findings that show a positive association between extreme heat events during winter and spring seasons and hay fever prevalence support the aforementioned 2 hypotheses of longer duration and greater concentration of pollen exposure. When temperatures in winter and spring are unusually warm, individuals may spend more time outdoors, bringing them in closer contact with outdoor pollen as well as other pollutants; however, national patterns of time spent outdoors are unknown.

Regardless of the exact underlying mechanism, our study is the first to link exposures to extreme heat events and increased odds of hay fever in the contiguous United States. Previous studies have shown that the frequency and intensity of such extreme events are increasing and will continue to do so in the coming decades.[19] Our data show the potential impact of

TABLE II. Unadjusted (model 1) and adjusted (models 2 and 3) odds ratios for hay fever among US adults*, NHIS 1997-2013

Variables	Categories	Model 1 OR (95% CI)	Model 2 OR (95% CI)	Model 3 OR (95% CI)
EHE_{95}		$P_{trend} < .001$	$P_{trend} < .05$	$P_{trend} < .05$
	Q1 (0-10 d)†	1.00	1.00	1.00
	Q2 (11-16 d)	1.06 (1.02-1.10)	1.05 (1.01-1.09)	1.05 (1.00-1.09)
	Q3 (17-24 d)	1.04 (1.00-1.08)	1.05 (1.00-1.09)	1.04 (1.00-1.09)
	Q4 (≥25 d)	1.07 (1.03-1.11)	1.07 (1.03-1.11)	1.07 (1.02-1.11)
Sex			$P_{trend} < .001$	$P_{trend} < .001$
	Male†		1.00	1.00
	Female		1.30 (1.27-1.33)	1.30 (1.27-1.33)
Race/ethnicity			$P_{trend} < .001$	$P_{trend} < .001$
	Non-Hispanic white		1.42 (1.35-1.49)	1.44 (1.37-1.51)
	Non-Hispanic black		1.09 (1.03-1.15)	1.09 (1.03-1.15)
	Hispanic†		1.00	1.00
	All other races and ethnicities		1.19 (1.10-1.28)	1.19 (1.10-1.29)
Age			$P_{trend} < .001$	$P_{trend} < .001$
	18-34 y†		1.00	1.00
	35-49 y		1.66 (1.61-1.72)	1.67 (1.61-1.73)
	50-64 y		1.59 (1.53-1.65)	1.59 (1.53-1.65)
	65 y and older		1.12 (1.08-1.17)	1.13 (1.08-1.18)
Education			$P_{trend} < .001$	$P_{trend} < .001$
	<High school/GED†		1.00	1.00
	High school/GED		1.02 (0.98-1.07)	1.02 (0.98-1.07)
	Some college		1.40 (1.33-1.46)	1.39 (1.33-1.45)
	Bachelor degree		1.50 (1.42-1.57)	1.48 (1.41-1.56)
	Graduate degree		1.68 (1.59-1.78)	1.67 (1.57-1.77)
Poverty status‡			$P_{trend} < .001$	$P_{trend} < .001$
	Less than 100%†		1.00	1.00
	100 to less than 200%		0.96 (0.92-1.00)	0.96 (0.92-1.00)
	200 to less than 400%		0.98 (0.94-1.02)	0.98 (0.94-1.02)
	400% or greater		1.05 (1.01-1.10)	1.04 (1.00-1.09)
Urban-rural classification§				$P_{trend} < .1$
	Large central metro			0.99 (0.94-1.03)
	Large fringe metro			1.00 (0.96-1.05)
	Medium metro†			1.00
	Small metro			0.99 (0.91-1.08)
	Micropolitan			0.92 (0.85-1.00)
	Noncore			0.89 (0.82-0.98)

CI, Confidence interval; *EHE_{95}*, extreme heat events—days where the daily maximum temperature value exceeded the county and calendar month specific 95th percentile threshold, calculated using 30 years of baseline data; *GED*, general education development; *NHIS*, National Health Interview Survey, *OR*, odds ratio.
Model 1: unadjusted; model 2: adjusted for gender, race/ethnicity, age, education, and poverty threshold; model 3: additionally adjusted for urban-rural classification.
*Includes sample adults 18 years and older with complete data for analytic covariates.
†Reference category.
‡Family income as a percent of poverty threshold.
§Counties were classified into urbanization levels based on the 2006 National Center for Health Statistics Urban-Rural Classification Scheme for Counties.

such increases on allergic diseases such as hay fever. Our study relied on a large (n = 505,386) nationally representative sample of the civilian noninstitutionalized US population. Our county-specific and calendar month-specific exposure metric generated using the 30 years of baseline data (1960-1989) enabled us to focus on changes in the frequency of extreme events relative to 30-year baseline rather than short-term weather phenomena. Furthermore, we were able to control for several socioeconomic characteristics including educational level, family income relative to the poverty threshold, and the urban-rural classification of the county, but they were not sensitive to further adjustment for region. Finally, we performed several sensitivity analyses, which established the robustness of our findings.

Our study also has several limitations. The term "hay fever" is a lay term used synonymously with seasonal allergic rhinitis.[10] However, it is unknown how often this term is used for general allergic rhinitis, which can include perennial symptoms caused by aeroallergens. Imprecise use of the term "hay fever" may be reflected in the NHIS. Furthermore, it is not clear if there are cultural, geographic, or other differences in how survey participants use the term "hay fever," and if use of a more general term such as "seasonal allergic rhinitis" would have yielded different prevalence estimates. However, the NHIS includes 2

TABLE III. Adjusted odds ratios (AORs [95% CIs]) for hay fever in adults*, NHIS 1997-2013, by season

Season	EHE_{95} Categories	P_{trend}	AOR (95% CI)	Percent
Spring		<.01		
	Q1 (0-2 d)†		1.00	32.19
	Q2 (3-4 d)		1.02 (0.98-1.06)	20.49
	Q3 (5-8 d)		1.04 (1.00-1.07)	28.25
	Q4 (≥9 d)		1.07 (1.03-1.12)	19.07
Summer		>.05		
	Q1 (0-2 d)†		1.00	41.46
	Q2 (3-4 d)		1.01 (0.97-1.05)	14.51
	Q3 (5-8 d)		1.02 (0.99-1.06)	21.09
	Q4 (≥9 d)		1.04 (1.00-1.07)	22.94
Fall		>.05		
	Q1 (0-2 d)†		1.00	35.14
	Q2 (3-4 d)		1.01 (0.97-1.04)	19.99
	Q3 (5-8 d)		1.00 (0.97-1.04)	29.63
	Q4 (≥9 d)		1.02 (0.98-1.07)	15.24
Winter		<.01		
	Q1 (0-2 d)†		1.00	32.72
	Q2 (3-4 d)		0.95 (0.92-0.99)	18.55
	Q3 (5-8 d)		0.98 (0.94-1.01)	28.84
	Q4 (≥9 d)		1.05 (1.01-1.09)	19.88

Adjusted for sex, age, race/ethnicity, education, family income as percent of poverty threshold, urban-rural classification, and month of interview.
All percentages were weighted using NHIS survey weights.
CI, Confidence interval; *EHE_{95}*, extreme heat events—days where the daily maximum temperature value exceeded the county and calendar month specific 95th percentile threshold, calculated using 30 years of baseline data; *NHIS*, National Health Interview Survey.
*Includes sample adults 18 years and older with complete data for analytic covariates.
†Reference category.

questions for children, one with the term "hay fever" and the other with the term "respiratory allergy," and similar magnitudes of differences by race and/or ethnicity are observed when responses to both questions are combined to estimate overall respiratory allergy.[41]

The NHIS is a multipurpose health survey, and as such, lacked information needed to more fully examine the effects of extreme heat events on hay fever. For instance, the NHIS survey does not collect exact data of onset of outcomes, degree of hay fever symptoms, or clinical indicators of allergen sensitization. In addition, we have no information on local pollen levels, which may have improved our understanding of the association between extreme heat events and reported allergies. From the cross-sectional design of the NHIS, we cannot establish a clear temporality in exposure to extreme heat events and hay fever, and our results may be affected by the length of time between exposure to extreme heat events and the recall of hay fever.[42] Moreover, hay fever may not capture the full spectrum of seasonal allergic rhinitis—a more complete measurement of seasonal respiratory allergies could result in a different observed association. Another limitation is the use of county of residence to define exposure for the NHIS respondents. However, this likely resulted in nondifferential measurement error, so the observed associations are an underestimation of the true measure. Finally, our study did not include additional risk factors including air pollution and pollen measurements in this multidimensional issue involving the climate-pollution-allergen effect.[43]

CONCLUSIONS

We investigated the impact of extreme heat events on the prevalence of hay fever among a nationally representative sample of the civilian noninstitutionalized US population from 1997 to 2013. We observed a modest, but significant, association between exposures to extreme heat events and hay fever prevalence. The findings were more pronounced for springtime extreme heat events. Our results provide empirical evidence of how extreme heat events, projected to an increase in frequency, duration, and intensity in the future, adversely impact allergic disease among US adults.

Acknowledgments

We acknowledge that the findings and conclusions in this paper are those of the authors and do not necessarily represent the views of the National Center for Health Statistics or the Centers for Disease Control and Prevention.

A.S., J.D.P., L.J.A., R.M., and L.Z. designed the research and directed its implementation; C.R.U., A.S., J.D.P., and L.J.A. co-wrote the manuscript; C.R.U. conducted the statistical analysis; C.J. prepared the exposure dataset; A.S., X.H., and F.C.C. supervised the statistical analysis and contributed to statistical modeling; all authors contributed to revision of the manuscript.

REFERENCES

1. Blackwell D, Lucas J, Clarke T. Summary health statistics for U.S. adults: National Health Interview Survey, 2012. Vital Health Stat 2014;(260): 1-161.
2. Schoenwetter WF, Dupclay L, Appajosyula S, Botteman MF, Pashos CL. Economic impact and quality-of-life burden of allergic rhinitis. Curr Med Res Opin 2004;20:305-17.
3. Meltzer EO, Blaiss MS, Naclerio RM, Stoloff SW, Derebery MJ, Nelson HS, et al. Burden of allergic rhinitis: allergies in America, Latin America, and Asia-Pacific adult surveys. Allergy Asthma Proc 2012;33(Suppl 1):S113-41.
4. Lancet The. Allergic rhinitis: common, costly, and neglected. Lancet 2008;371: 2057.
5. Blaiss MS. Allergic rhinitis: direct and indirect costs. Allergy Asthma Proc 2010;31:375-80.
6. Bousquet J, Khaltaev N, Cruz AA, Denburg J, Fokkens WJ, Togias A, et al. Allergic Rhinitis and its Impact on Asthma (ARIA) 2008 update (in collaboration with the World Health Organization, GA(2)LEN and AllerGen). Allergy 2008;63(Suppl 86):8-160.
7. U.S. Environmental Protection Agency. A Review of the Impact of Climate Variability and Change on Aeroallergens and Their Associated Effects (Final Report). Available from: http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=190306. Accessed November 16, 2013.
8. Seidman MD, Gurgel RK, Lin SY, Schwartz SR, Baroody FM, Bonner JR, et al. Clinical practice guideline: allergic rhinitis. Otolaryngol Head Neck Surg 2015; 152:S1-43.
9. World Health Organization. Allergic rhinitis and sinusitis. Available from: http://www.who.int/respiratory/other/Rhinitis_sinusitis/en/. Accessed April 4, 2016.
10. Wallace DV, Dykewich M, Bernstein DI, Blessing-Moore J, Cox L, Khan DA, et al. The diagnosis and management of rhinitis: an updated practice parameter. J Allergy Clin Immunol 2008;122:S1-84.
11. Bernstein JA. Allergic and mixed rhinitis: epidemiology and natural history. Allergy Asthma Proc 2010;31:365-9.
12. Michelozzi P, Accetta G, De Sario M, D'Ippoliti D, Marino C, Baccini M, et al. High temperature and hospitalizations for cardiovascular and respiratory causes in 12 European cities. Am J Respir Crit Care Med 2009;179:383-9.
13. Bhattacharyya N. Does annual temperature influence the prevalence of otolaryngologic respiratory diseases? Laryngoscope 2009;119:1882-6.
14. Beggs PJ. Adaptation to impacts of climate change on aeroallergens and allergic respiratory diseases. Int J Environ Res Public Health 2010;7:3006-21.

15. Lim YH, Hong YC, Kim H. Effects of diurnal temperature range on cardiovascular and respiratory hospital admissions in Korea. Sci Total Environ 2012;417:55-60.
16. D'amato G, Cecchi L, D'amato M, Liccardi G. Urban air pollution and climate change as environmental risk factors of respiratory allergy: an update. J Investig Allergol Clin Immunol 2010;20:95-102.
17. Field CB. Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation: Special Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York: Cambridge University Press; 2012.
18. Luber G, Knowlton K, Balbus J, Frumkin H, Hayden M, Hess J, et al. Climate change impacts in the United States: The Third National Climate Assessment. In: In: Melillo JM, Richmond TC, Yohe GW, editors. Washington, DC: US Global Change Research Program; 2014:220-56.
19. Edenhofer O, Pichs-Madruga R, Sokona Y, Farahani E, Kadner S, Seyboth K, et al. Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York: Cambridge University Press; 2014.
20. Bortenschlager S, Bortenschlager I. Altering airborne pollen concentrations due to the Global Warming. A comparative analysis of airborne pollen records from Innsbruck and Obergurgl (Austria) for the period 1980-2001. Grana 2005;44:172-80.
21. Emberlin J, Smith M, Close R, Adams-Groom B. Changes in the pollen seasons of the early flowering trees Alnus spp. and Corylus spp. in Worcester, United Kingdom, 1996-2005. Int J Biometeorol 2007;51:181-91.
22. Ziska LH, Beggs PJ. Anthropogenic climate change and allergen exposure: the role of plant biology. J Allergy Clin Immunol 2012;129:27-32.
23. Ziska L, Knowlton K, Rogers C, Dalan D, Tierney N, Elder MA, et al. Recent warming by latitude associated with increased length of ragweed pollen season in central North America. Proc Natl Acad Sci USA 2011;108:4248-51.
24. Frumkin H, Hess J, Luber G, Malilay J, McGeehin M. Climate change: the public health response. Am J Public Health 2008;98:435-45.
25. Patz JA, Campbell-Lendrum D, Holloway T, Foley JA. Impact of regional climate change on human health. Nature 2005;438:310-7.
26. Klein Rosenthal J, Kinney PL, Metzger KB. Intra-urban vulnerability to heat-related mortality in New York City, 1997-2006. Health Place 2014;30:45-60.
27. Basu R, Samet JM. Relation between elevated ambient temperature and mortality: a review of the epidemiologic evidence. Epidemiol Rev 2002;24:190-202.
28. U.S. National Oceanic and Atmospheric Administration. National Centers for Environmental Information (NCEI) formerly known as National Climatic Data Center (NCDC). Available from: http://www.ncdc.noaa.gov. Accessed April 4, 2016.
29. Romeo Upperman C, Parker J, Jiang C, He X, Murtugudde R, Sapkota A. Frequency of extreme heat event as a surrogate exposure metric for examining the human health effects of climate change. PLoS ONE 2015;10:e0144202.
30. U.S. Centers for Disease Control and Prevention. About the National Health Interview Survey. National Health Interview Survey. Available from: http://origin.glb.cdc.gov/nchs/nhis/about_nhis.htm. Accessed February 24, 2016.
31. United States Census Bureau. Poverty. Available from: https://www.census.gov/hhes/www/poverty/index.html. Accessed June 8, 2015.
32. Jackson KD, Howie L, Akinbami LJ. Trends in allergic conditions among children: United States, 1997-2011. NCHS Data Brief 2013;121:1-8.
33. Centers for Disease Control and Prevention. 2010 Imputed Family Income/Personal Earnings Files. Available from: http://www.cdc.gov/nchs/nhis/2010imputedincome.htm. Accessed May 1, 2016.
34. Ingram DD, Franco SJ. NCHS urban-rural classification scheme for counties. Vital Health Stat 2 2012;154:1-65.
35. RTI International. SUDAAN Homepage; 2014. Available from: http://sudaansupport.rti.org. Accessed November 4, 2014.
36. Ziska LH, Epstein PR, Schlesinger WH. Rising CO_2, climate change, and public health: exploring the links to plant biology. Environ Health Perspect 2009;117:155-8.
37. Zhang Y, Bielory L, Mi Z, Cai T, Robock A, Georgopoulos P. Allergenic pollen season variations in the past two decades under changing climate in the United States. Glob Chang Biol 2015;21:1581-9.
38. Beggs P. Impacts of climate change on aeroallergens: past and future. Clin Exp Allergy 2004;34:1507-13.
39. Rogers CA, Wayne PM, Macklin EA, Muilenberg ML, Wagner CJ, Epstein PR, et al. Interaction of the onset of spring and elevated atmospheric CO_2 on ragweed (*Ambrosia artemisiifolia* L.) pollen production. Environ Health Perspect 2006;114:865-9.
40. D'Amato G, Cecchi L. Effects of climate change on environmental factors in respiratory allergic diseases. Clin Exp Allergy 2008;38:1264-74.
41. Jackson KD, Howie LD, Akinbami LJ. Trends in allergic conditions among children: United States, 1997-2011. Available from: http://www.cdc.gov/nchs/products/databriefs/db121.htm. Accessed October 27, 2016.
42. Rothman KJ, Greenland S, Lash TL. Modern Epidemiology. Philadelphia, PA: Lippincott Williams & Wilkins; 2008.
43. De Sario M, Katsouyanni K, Michelozzi P. Climate change, extreme weather events, air pollution and respiratory health in Europe. Eur Respir J 2013;42:826-43.

TABLE E1. Unadjusted and adjusted (AORs [95% CIs]) for hay fever in adults*, NHIS 1997-2013, sensitivity analysis for EHE_{90}

EHE_{90} Categories	Model 1 OR (95% CI)	Model 2 OR (95% CI)	Model 3 OR (95% CI)
	$P_{trend} < .05$	$P_{trend} < .05$	$P_{trend} < .05$
Q1 (0-23 d)†	1.00	1.00	1.00
Q2 (24-34 d)	1.04 (1.00-1.09)	1.04 (1.00-1.09)	1.04 (1.00-1.08)
Q3 (35-46 d)	1.06 (1.02-1.10)	1.06 (1.02-1.10)	1.06 (1.01-1.10)
Q4 (≥47 d)	1.05 (1.01-1.10)	1.06 (1.01-1.10)	1.05 (1.01-1.10)

CI, Confidence interval; *EHE_{90}*, extreme heat events—days where the daily maximum temperature value exceeded the county and calendar month specific 90th percentile threshold, calculated using 30 years of baseline data; *NHIS*, National Health Interview Survey; *OR*, odds ratio.
Model 1: unadjusted; model 2: adjusted for sex, age, race/ethnicity, education, family income as percent of poverty and threshold; model 3: additionally adjusted for urban-rural classification.
*Includes sample adults 18 years and older with complete data.
†Reference category.

TABLE E2. Unadjusted and adjusted (AORs [95% CIs]) for hay fever in adults*, NHIS 1997-2013, sensitivity analysis for EHE_{99}

EHE_{99} Categories	Model 1 OR (95% CI)	Model 2 OR (95% CI)	Model 3 OR (95% CI)
	$P_{trend} < .001$	$P_{trend} < .001$	$P_{trend} < .001$
Q1 (0 d)†	1.00	1.00	1.00
Q2 (1-2 d)	1.05 (1.00-1.10)	1.03 (0.98-1.08)	1.03 (0.98-1.08)
Q3 (3-6 d)	1.11 (1.06-1.16)	1.09 (1.05-1.14)	1.09 (1.04-1.14)
Q4 (≥7 d)	1.09 (1.04-1.14)	1.08 (1.03-1.13)	1.08 (1.03-1.13)

CI, Confidence interval; *EHE_{99}*, extreme heat events—days where the daily maximum temperature value exceeded the county and calendar month specific 99th percentile threshold, calculated using 30 years of baseline data; *NHIS*, National Health Interview Survey; *OR*, odds ratio.
Model 1: unadjusted; model 2: adjusted for sex, age, race/ethnicity, education, family income as percent of poverty and threshold; model 3: additionally adjusted for urban-rural classification.
*Includes sample adults 18 years and older with complete data.
†Reference category.

TABLE E3. Adjusted odds ratios (AORs [95% CIs]) for hay fever in adults*, NHIS 1997-2013, sensitivity analyses for EHE_{90} and EHE_{99} by season

		Hay fever			
		AOR (95% CI)			
	Quartiles	Winter	Spring	Summer	Fall
EHE_{90}		$P_{trend} < .001$	$P_{trend} < .01$	$P_{trend} < .5$	$P_{trend} < .05$
	Q1 (0-4 d)†	1.00	1.00	1.00	1.00
	Q2 (5-6 d)	0.98 (0.93-1.02)	1.05 (1.01-1.10)	1.02 (0.97-1.06)	1.03 (0.99-1.07)
	Q3 (7-13 d)	0.97 (0.93-1.00)	1.03 (0.99-1.06)	1.02 (0.99-1.06)	1.01 (0.98-1.05)
	Q4 (≥14 d)	1.04 (1.00-1.08)	1.08 (1.04-1.12)	1.03 (1.00-1.07)	1.06 (1.02-1.11)
EHE_{99}		$P_{trend} < .5$	$P_{trend} < .01$	$P_{trend} < .05$	$P_{trend} < .5$
	Q1 (0 d)†	1.00	1.00	1.00	1.00
	Q2 (1 d)	1.02 (0.99-1.05)	1.00 (0.97-1.04)	1.01 (0.97-1.06)	1.01 (0.97-1.05)
	Q3 (2 d)	1.00 (0.96-1.05)	1.02 (0.98-1.07)	1.04 (0.99-1.09)	1.00 (0.95-1.05)
	Q4 (≥3 d)	1.04 (1.00-1.08)	1.07 (1.04-1.11)	1.05 (1.02-1.09)	0.97 (0.94-1.01)

CI, Confidence interval; *EHE_{90}*, extreme heat events—days where the daily maximum temperature value exceeded the county and calendar month specific 90th percentile threshold, calculated using 30 years of baseline data; *EHE_{99}*, extreme heat events—days where the daily maximum temperature value exceeded the county and calendar month specific 99th percentile threshold, calculated using 30 years of baseline data; *NHIS*, National Health Interview Survey; *OR*, odds ratio.
Adjusted for sex, age, race/ethnicity, education, family income as percent of poverty threshold, and urban-rural classification.
*Includes sample adults 18 years and older with complete data.
†Reference category.