
Changes in weather and the effects on pediatric asthma exacerbations

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Background: Pediatric asthma exacerbations may correlate with changes in weather, yet this relationship is not well defined.

Objective: To determine the effects of fluctuations in climatic factors (temperature, humidity, and barometric pressure) on pediatric asthma exacerbations.

Methods: A retrospective study was performed at 1 large urban hospital during a 2-year period (January 1, 2004, to December 31, 2005). Children presenting to the emergency department (ED) for an asthma exacerbation were included. Data on climatic factors, pollutants, and aeroallergens were collected daily. The relationship of daily (intraday) or between-day (interday) changes in climatic factors and asthma ED visits was evaluated using time series analysis, controlling for seasonality, air pollution, and aeroallergen exposure. The effects of climatic factors were evaluated on the day of admission ($T = 0$) and up to 5 days before admission ($T - 5$ through $T - 1$).

Results: There were 25,401 asthma ED visits. A 10% intraday increase in humidity on day $T - 1$ or day $T - 2$ was associated with approximately 1 additional ED visit for asthma ($P < .001$ and $P = .01$, respectively). Interday changes in humidity from day $T - 3$ to $T - 2$ were also associated with more ED visits ($P < .001$). Interday changes in temperature from $T - 1$ to $T = 0$ increased ED visits, with a 10°F increase being associated with 1.8 additional visits ($P = .006$). No association was found with changes in barometric pressure.

Conclusion: Fluctuations in humidity and temperature, but not barometric pressure, appear to influence ED visits for pediatric asthma. The additional ED visits occur 1 to 2 days after the fluctuation.

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INTRODUCTION

The incidence and prevalence of asthma have been increasing rapidly in the United States, especially among minority urban children and adolescents.^{1–3} Currently, 9 million US children younger than 18 years have been diagnosed as having asthma.^{4,5} Viral infections,⁶ tobacco smoke exposure,⁷ aeroallergens,⁸ and air pollutants⁹ have been shown to trigger pediatric asthma exacerbations.

Parents and patients often attribute worsening asthma symptoms and exacerbations to “changes in the weather.” Studies that have examined the effect of weather on asthma have shown that extreme weather conditions may play a role in asthma epidemics.^{7,10–14} Reports have indicated that such epidemics may be precipitated by sudden decreases in temperature,^{10,14} thunderstorms,¹⁵ and severe and sudden rain.¹⁶ Other studies in US inner cities have shown that asthma exacerbations may be correlated with days of low tempera-

ture and humidity,¹⁴ high barometric pressure,¹³ and cold fronts with sudden decreases in temperature.¹⁴

These studies imply that weather may affect asthma exacerbations. However, whether the crucial meteorological parameters relate to current conditions or are delayed by some days remains unclear. Most of these studies looked at absolute values of climatic factors, rather than fluctuations or changes in the parameters. In addition, no previous study to our knowledge has attempted to determine the effects of weather changes while controlling for pollutant and aeroallergen data. The purpose of this study was to determine the role that weather fluctuations may play in asthma attacks. Specifically, we investigate daily (intraday) and day-to-day (interday) fluctuations in temperature, barometric pressure, and humidity as predictors of pediatric asthma exacerbations in an urban setting.

METHODS

This single-center study was performed at the Children’s Hospital of Michigan (CHM) in Detroit, Michigan. This hospital serves as the main source of emergency department (ED) care for pediatric asthma patients in urban Detroit. A 2-year retrospective ecologic study covering ED admissions from January 1, 2004, through December 31, 2005, was conducted. All patients 1 to 18 years of age who presented to the CHM with a primary diagnosis of an asthma exacerbation were eligible for inclusion in the study. Patients were ex-

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cluded from the study if they did not reside within the Detroit postal zip codes.

Climatic Factors

Data on climatic variables (barometric pressure, humidity, temperature) were retrieved from the National Climatic Data Center, which performed measurements at the Detroit City Airport weather station. The average, maximum, and minimum values were recorded for temperature and relative humidity. For barometric pressure, only average daily levels were provided.

Air Pollution

Air quality data for Wayne County were obtained from the Environmental Protection Agency. Data collected included nitrogen dioxide, sulfur dioxide, ozone, carbon monoxide, particulate matter with aerodynamic diameter less than 10 μm (PM_{10}), and particulate matter with aerodynamic diameter greater than 2.5 μm ($\text{PM}_{2.5}$). Sulfur dioxide was measured by the UV fluorescence method. Nitrogen dioxide (daily average parts per million) was measured by chemiluminescence. Ozone was measured by the UV absorption technique in Detroit and recorded as daily averages (parts per million) during the summer months. PM_{10} and $\text{PM}_{2.5}$ were measured hourly and expressed in micrograms per cubic meter.

Seasonal Allergens

Aeroallergen data (tree, grass, weed, and outdoor mold counts) were obtained from the nearest certified pollen station, approximately 17 miles from our institution. Pollen was collected approximately 2 to 3 times a week, but more frequently through the spring and early fall season. Pollen and mold spores were identified and counted via electron microscope. Counts were not available during the winter months, which is standard for the pollen station reporting.

Statistical Analysis

This 2-year retrospective study was evaluated using time series analysis, 1 of the most effective ways to analyze time-dependent parameters.¹⁷ The primary objective was to determine whether daily variations in temperature and humidity correlated with pediatric asthma exacerbations. A secondary objective was to determine what degree of change was necessary to influence pediatric asthma exacerbations. The variables for analysis included date of visit, week of the year, weekend or holiday indicator, pollutant concentrations (nitrogen dioxide, sulfur dioxide, ozone, PM_{10} , and $\text{PM}_{2.5}$), climatic factors (temperature, humidity, and barometric pressure), and aeroallergen data (pollen counts for trees, grass, weeds, and mold).

We examined the effect of change in each climatic factor within a day (intraday) and between consecutive days (interday). Intraday values were calculated by subtracting the maximum from minimum value for temperature and humidity, and interday values were calculated by subtracting average daily values for each of the 3 climatic factors. The effects of climatic factors were evaluated on the day of admission ($T = 0$) and up to 5 days before admission ($T - 5$ through $T - 1$).

The study period consisted of a total of 731 days (Table 1). Most air pollutants had daily records, but ozone was not measured every day. Pollen and mold counts were also not collected every day. To address this limited data set, 2 models were constructed. Model 1 excluded pollen, mold, and ozone data but included all other variables for all days. Model 2 included all days that all of the variables (climatic factors, pollutant, and aeroallergen) were present.

Semiparametric regression with the generalized additive model (GAM)¹⁸ was used to model the daily counts of asthma admissions in the ED. Analysis of the data showed a normal distribution with a mean daily asthma admission rate of 35 emergency visits (SD, 12) during the 2-year study period. The association of climatic factors, aeroallergens, and pollutants with asthma ED visits was also analyzed using the GAM. This flexible approach treats climate parameters and air pollutants as smooth functions in the same manner as the time (trend and season) covariate and is therefore suitable for controlling confounding factors.

We established an initial core model, which included spline smooth functions of week, mean daily temperature, average humidity, and holiday or weekend indicator. The effect of mean temperature and humidity on the day of admission and up to 5 days before was tested using the Akaike Information Criteria (AIC)¹⁹ and autocorrelation correction in GAM. Testing for any residual autocorrelation was found to be nonsignificant. The lagged variables with minimized AIC were selected into the initial core model. After the initial core model was built, all environmental pollutants were controlled before examining the predictors of interest (interday and intraday changes in temperature and humidity). The same univariate selection procedure as for the mean temperature and humidity was repeated for each of the environmental pollutants, and then all selected pollutant variables were included into the finalized core model before further investigation.

All predictors of interest for the day of admission and up to 5 days previously were tested separately for their effect on the

Table 1. Daily Asthma Admissions, Meteorological, Aeroallergen, and Air Pollution Data

Variable	No. of days	Mean (SD)
ED visits per day	731	35 (12)
Average temperature, °F	703	51.58 (19.58)
Average humidity, %	731	68.46 (12.43)
Nitrogen dioxide, ppm	716	0.017 (0.08)
Carbon monoxide, ppm	730	0.56 (0.35)
$\text{PM}_{2.5}$, ppm	681	15.07 (9.61)
PM_{10} , ppm	696	35.41 (22.58)
Sulfur dioxide, ppm	691	0.0054 (0.01)
Ozone, ppm	449	0.036 (0.02)
Pollen, grains/d	276	101.62 (208.38)
Mold, spores/d	276	5,303.24 (2,362.05)

Abbreviations: ED, emergency department; $\text{PM}_{2.5}$, particulate matter with aerodynamic diameter greater than 2.5 μm ; PM_{10} , particulate matter with aerodynamic diameter less than 10 μm .

number of admissions using the procedures described herein. The lagged predictors with the strongest effect (minimized AIC) were then added jointly into the core model to build a final GAM model. The final model includes main effects, and evaluation of any significant interactions was also performed.

RESULTS

Descriptive statistics for the admission, meteorological, aeroallergen, and air pollutant data are given in Table 1. There were 25,401 pediatric asthma admissions to the CHM during the 731-day study period. Asthma morbidity was increased during the months of February, September, and October in both years (Fig 1). The daily mean temperature for the 2-year period varied from 7°F to 87°F. The daily mean relative humidity varied from 30% to 100% and barometric pressure from 29.39 to 32.39 mm Hg.

Model 1

The core model that examined pollutant and climatic variables found that nitrogen dioxide on day $T - 4$ ($\beta = 291.1$, $P < .001$), sulfur dioxide on day $T - 2$ ($\beta = 410.2$, $P < .001$), and average humidity on day $T - 2$ ($\beta = 0.11$, $P = .005$) were significantly associated with admissions. Entering these factors into the final GAM model, we found that asthma admissions were significantly associated with temperature and humidity changes. As indicated in Table 2, intraday and interday humidity changes 2 days before the examined admission date were highly statistically significant ($P < .001$). These results indicate that a decrease in humidity of 10% from day $T - 3$ to day $T - 2$ correlated with 1.3 additional pediatric asthma exacerbations. Similarly, a 10% increase in relative humidity on day $T - 2$ was associated with 1.1 additional pediatric asthma exacerbations.

Interday temperature change on the day of asthma admissions was also statistically significant ($P = .006$), indicating that an increase of 10° from day $T - 1$ to day $T = 0$ would predict 1.8 additional pediatric asthma exacerbations. In addition, a 10° intraday temperature increase on the day of asthma admission (day $T = 0$) was associated with 1.1 additional asthma exacerbations, although this did not reach statistical significance ($P = .07$). Barometric pressure was not associated with asthma admissions ($P = .17$). When the data were analyzed for interactions between intraday and interday temperature and humidity changes, no significant interactions were identified (data not shown).

Model 2

The core model that examined pollutant, aeroallergen, and climatic variables found that nitrogen dioxide on day $T - 4$ ($\beta = 256.5$, $P < .001$) and sulfur dioxide on day $T - 2$ ($\beta = 266.1$, $P < .001$) were associated with admissions. Ozone on day $T - 1$ was also associated with admissions, although this did not reach significance ($\beta = 57.9$, $P = .07$). As indicated in Table 3, after these factors were entered into the GAM model, interday humidity change from day $T - 3$ to day $T - 2$ and intraday humidity change 1 day before day of admission (day $T - 1$) were statistically significant ($P = .04$ and $P = .01$, respectively). These results are consistent with model 1. They indicated that a 10% decrease in relative humidity from day $T - 3$ to day $T - 2$ was associated with 0.8 additional pediatric asthma exacerbations. Also, a 10% within-day increase in relative humidity on day $T - 1$ correlated with 1.0 additional pediatric asthma exacerbations.

A 10°F increase in intraday temperature on the day of admission ($T = 0$) was associated with 1.5 additional asthma ED admissions, although this did not reach significance ($P =$

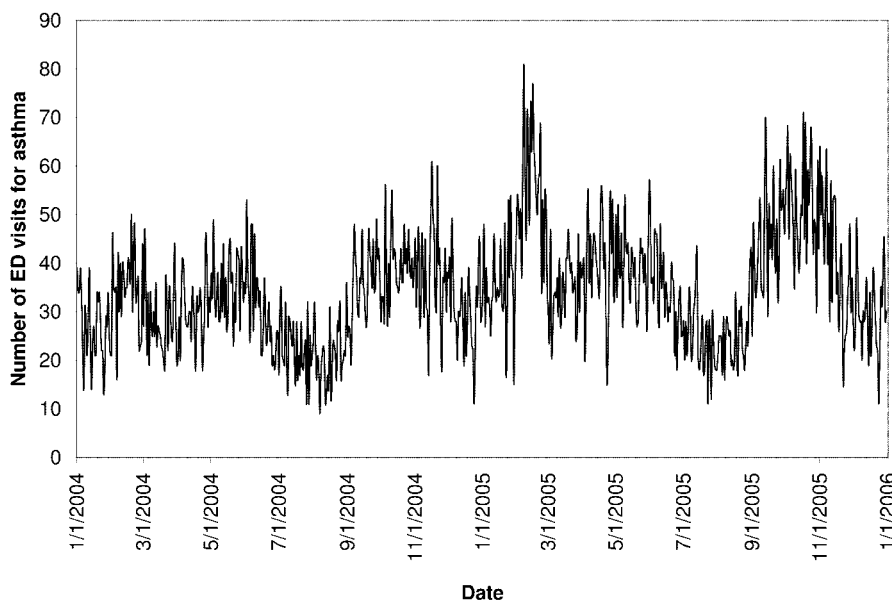


Figure 1. Pediatric asthma emergency department (ED) visits from January 1, 2004, through December 31, 2005.

Table 2. Role of Temperature, Humidity, and Barometric Pressure on Asthma Exacerbations for All Variables Except For Pollen, Mold, and Ozone (Model 1)

Predictor	Day	β (SE)	P value
Interday humidity change	T - 3 to T - 2	-0.13 (0.04)	<.001
Intraday humidity change	T - 2	0.114 (0.034)	<.001
Interday barometric pressure	T - 1 to T = 0	-2.30 (1.63)	.17
Interday temperature change	T - 1 to T = 0	0.176 (0.06)	.006
Intraday temperature change	T = 0	0.11 (0.062)	.07

Table 3. Role of Temperature, Humidity, and Barometric Pressure on Pediatric Asthma Emergency Department Visits for All Variables (Model 2)

Predictor	Day	β (SE)	P value
Interday humidity	T - 3 to T - 2	-0.076 (0.04)	.04
Intraday humidity	T - 1	0.10 (0.04)	.01
Interday barometric pressure	T - 1 to T = 0	-3.3 (2.47)	.18
Interday temperature	T - 1 to T = 0	0.15 (0.08)	.07
Intraday temperature	T = 0	0.07 (0.08)	.40

.07). The number of asthma admissions was not found to be associated with barometric pressure or intraday temperature. Again, we analyzed the data for interactions between interday and intraday humidity and interday temperature change. Similar to results in model 1, no significant interactions were noted (data not shown).

DISCUSSION

This study shows a strong relationship between temperature and humidity fluctuations and pediatric asthma exacerbations. Notably, these correlations were seen after controlling for levels of airborne pollutants and common aeroallergens. Previous studies of the relationship between weather parameters and asthma exacerbations have often viewed weather as acting through secondary effects on pollutant or aeroallergen levels or have failed to rule out such effects. To our knowledge, this is the first study to show weather effects that are demonstrably independent of changes in pollutant and aeroallergen levels.

Patients experiencing an asthma attack often complain that weather fluctuations are a major trigger. In fact, the latest National Institutes of Health guidelines list "change in weather" as a possible precipitating factor for asthma²⁰ but do not cite any references for this opinion. In fact, a review of the literature reveals few studies that specifically address this topic. Our study had the benefit of a large, active ED located in an urban environment. As noted in Table 1, the average number of ED visits for asthma per day was 35, more than any of the other studies we reviewed.

Studies examining correlations between weather and asthma-related ED admissions have typically looked only at conditions on the day of presentation, although some have also looked at previous days, as we did. Results have been inconsistent, possibly reflecting influences of methods, location, climate, and influences of uncontrolled weather-related factors. Interactions between factors may also be significant. For example, Rossi et al²¹ found that in Finland neither

meteorological factors nor aeroallergens had an independent effect, but temperature modified the effects of air pollutants. Temperature also modified the effect of air pollution in a Spanish study.²²

Barometric pressure has also been associated with asthma exacerbations. High barometric pressure was associated with an increase in ED visits for pediatric asthma in a study performed in Israel.¹ In Japan, barometric pressure was higher on both the day of admission and the day before, whereas relative humidity was lower on both days.⁷ A greater change in temperature on the previous day was also associated with ED visits for asthma in this setting.

Not all studies have found a significant effect of barometric pressure, however. In Bermuda, which has a relatively equable climate and a virtual absence of industrial pollution, both lower relative humidity and lower temperature, but not barometric pressure, were associated with an increased number of ED visits.¹⁰ Strikingly, a Swedish study²³ found that temperature was the only important meteorological parameter but that results were different for children and adults. Increased numbers of asthma exacerbations were associated with low temperatures in children but with high temperatures in adults.

Our findings point to the importance of changes in temperature and relative humidity rather than to the absolute values of these parameters. This finding is similar to a previous study in which asthma ED visits were associated with changes in temperature and heat content during an afternoon but not with the absolute values of these parameters.²⁴ Interestingly, an increased number of asthma admissions was associated both with a decrease in relative humidity between days T - 3 and T - 2 and with an increase in humidity during day T - 2. In both instances, a 10% variation accounted for 1 additional ED visit. Therefore, the timing and magnitude of change in humidity, rather than the direction, may be a more important influence on asthma exacerbations.

Temperature change between day T - 1 and the day of admission was significantly associated with admissions when

pollen, mold, and ozone levels were not controlled (model 1) and approached significance when the analysis was restricted to days for which these values were available (model 2). Temperature change on the day of admission ($T = 0$) approached significance in model 1 but not in model 2. In both models, it appeared that a 10° increase in temperature would account for an additional 1 to 2 patients with asthma exacerbations presenting to the ED.

Changes in barometric pressure, such as might be associated with a thunderstorm or passage of a frontal system, were not significant at any time. This finding is in contrast to the importance of absolute barometric pressure seen in studies conducted elsewhere.^{7,24} Our model allowed us to control for the absolute barometric pressure because we were interested in intraday and interday change. The earlier studies also did not control for aeroallergen and pollution data. These differences may explain the divergent outcomes.

It is well understood that weather patterns can affect levels of both industrial pollutants and aeroallergens, and meteorological parameters have often been examined in this context. We controlled for these factors, however, especially in model 2, which renders them unlikely explanations for the correlations we observed. An increase in viral infections remains possible, although it is not clear why such an increase in viral infections should be associated with intraday and interday fluctuations in climatic factors. We attempted to control for seasonal fluctuations in viral infections by adding a "week of the year" variable to the model. It has been reported that the exercise capacity of asthmatic individuals is greater in humid air than in dry air,²⁵ but in this case one would anticipate a correlation with the relative humidity on the day of presentation rather than with recent changes. We also acknowledge that this is a retrospective study and therefore is inherently subject to limitations such as misclassification of asthma cases.

Our study is 1 of the few that have examined the possibility that the weather 1 or 2 days before the asthma exacerbation may be as important as that on the day of admission. It is also 1 of the few to show that exacerbations may be associated more with changes in the weather than with current meteorological parameters. Further investigation of these variables will help clarify factors involved in asthma exacerbations, which deserves further exploration.

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