

Asthma admissions and thunderstorms: a study of pollen, fungal spores, rainfall, and ozone

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Summary

Asthma admissions have been reported to increase during thunderstorms. In some cases, this has been attributed to rises in pollen or fungal spore counts occurring alone or in combination with rainfall. We tested the hypothesis that thunderstorms in general are associated with asthma admissions, and investigated the possible roles of pollen, fungal spores, ozone, and other meteorological factors. We obtained data on multiple pollen and fungal spore counts, rainfall, temperature, ambient ozone concentrations, and asthma admissions for 32 dates when lightning strikes were recorded in the Cardiff/Newport area, and 64 matched dates in previous and subsequent years. Poisson regression models were used to investigate associations between admissions and proposed causative

environmental factors. The number of asthma admissions was greater on days with thunderstorms than on control days ($p < 0.001$). There were no associations or interactions between admissions and any pollen or fungal spore counts or rainfall. After adjusting for thunderstorms, there was an independent association between increasing ozone concentration, when temperature was included in the model, and increasing admissions ($p = 0.02$). Asthma admissions are increased during thunderstorms. The effect is more marked in warmer weather, and is not explained by increases in grass pollen, total pollen or fungal spore counts, nor by an interaction between these and rainfall. There was an independent, positive association between ozone concentrations and asthma admissions.

Introduction

Individual thunderstorms have coincided with up to 10-fold rises in asthma admissions, and a small increase in asthma admissions has been reported to be associated with thunderstorms in general.^{1–4} This association has not been explained; it has been suggested that high concentrations of pollen or fungal spores preceding a thunderstorm may be important,^{5,6} but we have been unable to find anything in the literature to suggest an effect of pollen counts on asthma admissions in the absence

of thunderstorms. Rain may result in the release of smaller, respirable particles from pollen grains which are normally too large to reach the small airways,⁷ but again we found nothing in the literature to suggest that rainfall and high pollen counts have a synergistic effect in increasing asthma admissions. Grass pollen and the spores of *Didymella exitialis* and *Sporobolomyces* have been implicated in specific circumstances.⁸ Acute changes in other meteorological factors such as

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temperature or pressure might also be important. Increasing ozone exposure may also result in exacerbation of asthma symptoms,^{9–11} the effect of which may be aggravated by aeroallergens.^{12,13} We report here a study intended to investigate any association between asthma admissions and thunderstorms in relation to pollen counts, fungal spores and meteorological data. Since there is an association between thunderstorms and ambient ozone concentrations,¹⁴ we also investigated whether changes in the concentration of this gas might be relevant.

Methods

Airborne pollen and fungal spores in central Cardiff have been collected and counted by the Sully Hospital Asthma and Allergy Research Unit since the 1950s. Computerized hospital records provided information on asthma emergency admissions (ICD9 codes 493.0, 493.1 and 493.9) for Cardiff and Newport. We ascertained the days on which lightning strikes had been recorded, within 10 km of the centre of Cardiff, between January 1990 and December 1996: these were defined as thunderstorm days. The same calendar dates on the previous and subsequent years were used as controls.

Meteorological Office data on mean daily ozone concentrations for Cardiff were obtained from the Internet. Data on daily minimum and maximum temperature and total rainfall (in mm) in the 24-h period 09:00 to 09:00 GMT were obtained from the Met. Office in Glasgow and relate to the Cardiff Airport measurement site.

Statistical analysis used SPSS version 8.0 and Stata version 6.0. Comparisons of numbers of admissions, meteorological and exposure variables between thunderstorm and control days were made initially using Mann-Whitney tests. Preliminary analyses of many types of pollen and fungal spore in relation to asthma admissions were limited to Spearman's correlations. However total pollen count and total fungal spore count were investigated in greater detail. These counts had highly skewed distributions and were transformed using natural logs (0.5 was added before taking log values in order to avoid taking logs of zero counts). This allowed greater use of parametric methods that require approximately normally distributed data. Poisson log-linear regression modelling was used to examine the effects on the number of daily asthma admissions, on 32 thunderstorm days and 64 control days, of multiple factors and the interactions between these factors. The factors selected for consideration in the multiple regression models

were based on findings from the initial analyses and hypotheses from the literature. Early analyses included a season term, but in subsequent analysis this was replaced by average or maximum temperature, which was considered to be more objective.

Results

Lightning strikes were recorded on 32 separate days between January 1990 and December 1996, the daily number of strikes ranging from 1 to 16. The number of asthma admissions ranged from none to 12, with a mean of 4.5 and SD of 2.5. Average numbers of daily asthma admissions were lower in the summer months (4.1 for May through September) than in the rest of the year (5.1 for October to April inclusive) ($p=0.04$). Overall, there were more admissions on thunderstorm days ($p=0.04$), but when analysed in the two seasons this excess was confined to the summer ($p<0.001$, Figure 1). There was a small significant Spearman's correlation between the number of strikes and the number of admissions ($r=0.25$).

Spearman's correlation coefficients between the number of asthma admissions and counts of over 100 individual pollens and spores were considered separately, but none was positively associated at the 1% significance level. Specifically, counts of *Sporobolomyces* and hyaline septate spores (including *Didymella exitialis*) and *Graminaceae* (grass) pollen were not positively or significantly correlated with asthma admissions. Therefore only total pollen and fungal spore counts were considered for inclusion in further analyses. Total pollen counts, which ranged from 0 to 693/m³, were higher in summer than in winter ($p=0.004$) and somewhat lower on the days of thunderstorms (Figure 2).

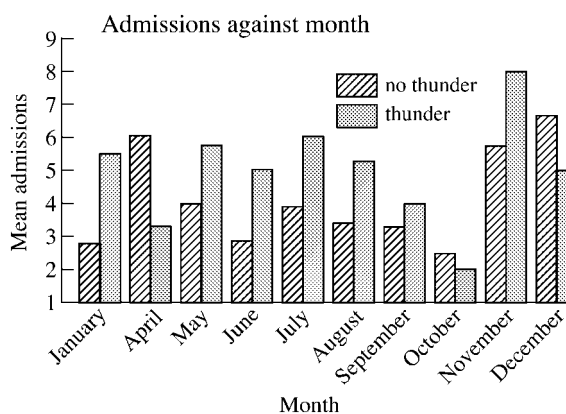


Figure 1. Mean number of admissions against month, for days divided according to the presence or absence of thunder.

Fungal spore counts, which ranged from 0 to 17 620/m³, were significantly higher in summer ($p < 0.001$) but not significantly so on the days of thunderstorms (Figure 3). Both pollen and fungal spore counts were correlated with temperature ($r = 0.36$ and $r = 0.82$, respectively). There were no significant Spearman's correlations between either pollen or fungal spore counts and asthma admissions ($r = -0.07$ and $r = -0.09$).

Rainfall data were available for all 96 thunderstorm and control days. Daily rainfall varied from 0 to 85 mm, and was significantly higher during thunderstorms ($p = 0.002$). There was no relationship between asthma admissions and rainfall ($r = 0.09$). We found no evidence of an interaction between rainfall and grass counts, total pollen counts or fungal spores in relation to asthma admissions.

Ozone concentrations had been recorded for 66 of the 96 days. They tended to be higher on high temperature days ($r = 0.32$) and the highest levels were recorded during thunderstorms in the

summer. Ozone concentrations on days prior to thunderstorm days were significantly higher than on days prior to non-thunderstorm days (medians 19 and 15 mg/m³, respectively, $p = 0.03$). They were not significantly associated with admissions in the univariate analysis. However, after allowing for the effects of thunderstorms and season, there was a positive relationship between asthma admissions and increasing ozone in summer ($p = 0.02$). Thus there were higher numbers of asthma admissions on summer days with high ozone than would have been expected if ozone and temperature had independent effects. This model, including ozone, season and thunderstorms, explained 13.7% of the variation in asthma admissions.

While neither fungal spore count nor ozone was significantly associated with asthma admissions when examined separately, their interaction was considered, in case sensitivity to fungal spores could be influenced by exposure to ozone. Again, this was found not to be significantly associated with admissions ($p = 0.11$). There were no obvious relationships between admissions and any of the temperature variables. However, there were large positive correlations of about 0.5 between temperature variables and ozone, in keeping with higher ozone concentrations on hotter days. Plots of asthma admissions against any of the temperature variables did not suggest that there were any strong relationships, and none of the temperature variables was significant when included as the only main effect in a regression model for asthma admissions.

Neither ozone nor maximum temperature was significant in a Poisson model for asthma admissions when considered separately, but their interaction was significant ($p = 0.04$). However the fit was poor, and explained little of the daily variation in admissions. When thunder was included as well, however, the model explained 12% of the variation in asthma admissions. This model was improved by replacing ozone on the day of admission by ozone on the day prior to the thunderstorm or control day. It fitted the data better and had incident rate ratios (95% CIs) and p values for thunder of 1.300 (1.008, 1.676), 0.043; maximum temperature of 0.950 (0.920, 0.980) 0.001; previous day's ozone of 0.982 (0.955, 1.009) 0.183; and the interaction of maximum temperature and previous day's ozone of 1.001 (1.000, 1.003) 0.021. Thunder days were thus associated with having 30% higher admissions. High maximum temperature following a high ozone day together were also associated with a small increase in admissions, higher than would have been predicted from the independent effects of temperature and ozone. A corresponding model, including average

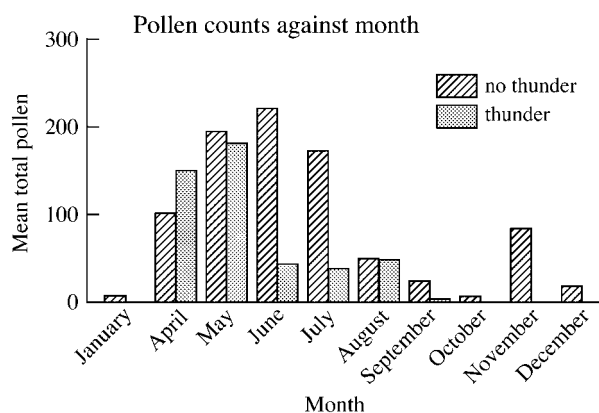


Figure 2. Mean pollen count against month for days divided according to the presence or absence of thunder.

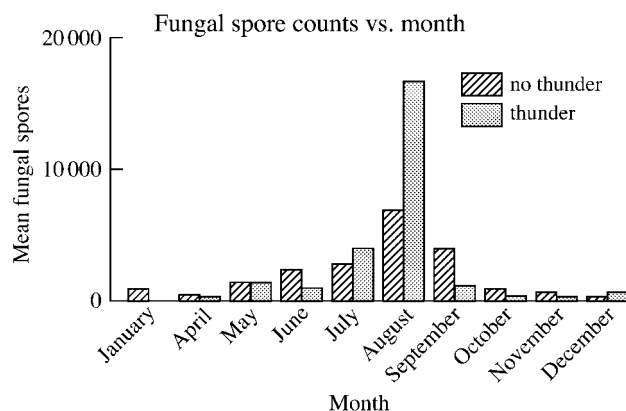


Figure 3. Mean fungal spore count against month for days divided according to the presence or absence of thunder.

Table 1 Predicted asthma admissions under different thunderstorm, ozone and temperature conditions; ozone was as measured on the day prior to the admissions

	Ozone (ppb)	Maximum temperature $\geq 17^{\circ}\text{C}$		Maximum temperature $< 17^{\circ}\text{C}$	
		Prediction	95%CI	Prediction	95%CI
Thunderstorm	≥ 16	5.2	5.0–5.5	6.1	5.9–6.3
	< 16	4.2	3.9–4.5	6.4	6.0–6.7
No thunderstorm	≥ 16	3.9	3.7–4.1	4.5	4.2–4.8
	< 16	3.1	2.8–3.4	4.7	4.5–5.0

temperature instead of maximum temperature, was consistent and had similar odds ratios.

A simpler model for asthma admissions including thunder, maximum temperature as higher or lower than 17°C , ozone on the previous day as higher or lower than 16 ppb, and the two-level interaction between maximum temperature and ozone was used to obtain predicted values of asthma admissions. These predictions and 95% CIs are displayed in Table 1.

Discussion

This study confirms the association between thunderstorms and increased hospital admission with asthma, an effect most marked in the summer months. However, our data do not suggest that this can in general be attributed to the concentrations of total or individual pollen grains or fungal spores, or to an interaction between these and rainfall. We were also able to confirm an association between asthma admissions and ozone levels but this was independent of the effect of thunderstorms. These results must be viewed in the knowledge that our study has limited power, due to the relatively small numbers of thunderstorms that occur even over an extensive period of study. In addition, asthma admissions are used as a surrogate for the severity of asthma in the community, and this is likely to be imprecise. Outdoor measurements of temperature, ozone, pollen and fungal spores are also only likely to be surrogates for individual exposures.

There have been several reports of an association between increased asthma admissions and one or more thunderstorms,^{1–4} but this is the first study to support this using date-matched control days. This approach has enabled us to characterize those thunderstorms that are associated with increases in admissions, and to suggest that the association is present mainly in warmer weather. Several possible explanations of the association and its seasonal variation suggest themselves.

First, any weak effect in winter may be obscured by the dominant effect of viral infections in causing asthma exacerbations in that season.^{15,16} This provides a plausible explanation for the effect of season, but fails to suggest a mechanism by which thunderstorms exacerbate asthma. Secondly, thunderstorms may be associated with changes in the allergen load in the air, an effect that would be most marked in summer when pollen and spore concentrations are highest. We have not been able to demonstrate any increase in allergen load in association with thunderstorms, nor have we been able to demonstrate an association between allergen load and asthma admissions. If a general association between allergen load and asthma symptoms existed, it is likely it would be well supported in the literature, and that peaks in pollen counts or fungal spores would result in an excess of asthma admissions. There is little evidence that is the case,¹⁷ and, if it were, would presuppose an at-risk, sensitized population of asthmatics. This is unlikely with respect to fungal spores. This is not to say that individual episodes in other geographical areas have not been caused by local increases in specific fungi or pollens; such associations are quite likely. However, the broad range of our database of aeroallergens has allowed us to investigate all the common UK spores and pollens, and we found no general effect, even when we took account of rainfall, which may cause disruption of pollen grains and release of allergenic particles. We are unable to find evidence in the literature of synergism between fungal spore counts and rainfall outside the context of thunderstorms.

Thirdly, thunderstorms may cause rises in concentrations of photochemically-generated irritant gases in the air, an effect that would be greater in summer when sunshine is more prevalent. There is a theoretical association between thunderstorms and high ozone levels, the storm activity causing an influx of stratospheric ozone into the troposphere.¹⁴ Ozone levels generally are higher in summer, as a result of sunlight acting on precursor gases such as nitrogen dioxide and volatile organic

compounds. Unlike the effect of allergen load, the effect of increasing ozone exposure on population asthma symptoms in the absence of thunderstorms is clearly documented in the literature.^{9–13} We have been able to confirm the role of ozone in increasing asthma admissions under certain temperature conditions, but have found this effect to be independent of thunderstorms.

Our study was designed to test the previously observed association between asthma admissions and thunderstorms and to investigate hypothetical explanations. We are aware that this study had limited power, and so we cannot exclude the possibility that we have missed other interactions. However, no previous paper has included as many thunderstorms occurring under such a variety of different conditions and investigated such a range of possible explanations. We have confirmed the association and found it to be associated with higher temperatures. We have had less success in defining an explanation for the association, but have found no evidence for several suggested ones. We have been unable to find any evidence in support of the allergen load hypothesis as a general explanation. While we have found an association between asthma admissions and ozone concentrations, this was independent of thunderstorms. The association therefore remains to be explained. One possibility that has not so far been investigated, to our knowledge, is an alteration in the ionization of the air as a result of thunder activity. Previous reports have variously suggested that air ions may exacerbate or protect against asthma.^{18,19} It is possible that greater knowledge of air ionization in relation to thunderstorms and asthma morbidity may provide an explanation.

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