

Effects of aeroallergens on the lung function of primary school children at two contrasting sites in South-East England

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Abstract

It is well known that airborne pollen can affect lung function and general well-being. This is particularly true for individuals predisposed to respiratory complications (for example sufferers from hay fever and asthma). Globally, there is evidence that asthma incidence is increasing in children over 2 years of age, and, within the UK, the south-east of England has the highest incidence for all ages in the population. Variations in lung function of school children (measured as peak expiratory volume) with associated changes in airborne pollen and pollution loads at two contrasting sites (one urban, the other rural) within the Medway Towns in south-east England were measured during the pollen season in 1998. Children of similar ages and social backgrounds participated in the studies, and account was taken of children with known respiratory problems. Pollen, pollution and weather data were collected at each site.

A picture has been obtained of how changes in local and regional aeroallergen levels, as well as other environmental factors, effect public health in this region of England. Children at the urban site produced consistently better average lung function results, although more pollen was caught there. At the rural site there was generally no relationship between pollen counts and lung function. As expected, lung function was lower on anticyclonic days when there was less mixing in the air. There is strong evidence that episodes of air pollution were more important in promoting reduced peak expiratory flows than specific aeroallergen levels alone. Whilst this requires further investigation, it confirms that attributing changes in lung function solely to pollen levels may sometimes be misleading.

1. Introduction

There is evidence that, world-wide, the prevalence of asthma and related conditions is increasing, especially in western countries (Burr et al., 1989; Ninan and Russel, 1992; Omran and Russel, 1996). Although there is no evidence to suggest that this increase is caused by air pollution initiating development of the disease, the adverse health effects of many atmospheric pollutants are now well-known and air pollution may be a significant trigger of asthmatic episodes in susceptible individuals (see for example Wang et al., 1999). In the UK, ambient levels of carbon monoxide (CO), sulphur dioxide (SO₂), oxides of

nitrogen (NO_x), tropospheric ozone (O₃) and particulate material of 10 micrometres (µm) in diameter (PM₁₀) are regularly monitored as part of a country-wide pollution monitoring and forecasting initiative (Harrison, 1997; Fowler et al., 1997). With the exception of O₃, these pollutants are released from road vehicles, power stations burning fossil fuels, mining and quarrying (SEIPH, 1998). Additionally, natural particulates may be produced from the environment, for example as windblown dusts and suspended sea salts. Of these, diesel vehicles are the greatest source of particulates (Moon and Donald, 1997; British Lung Foundation, 1998). Vehicle exhausts are also the primary source of nitrogen oxides, whilst most

atmospheric SO₂ is produced through power generation (Fowler et al., 1997). Tropospheric ozone, a highly reactive irritant gas and a strong oxidising agent, is produced through a complex series of chemical reactions from the sunlight-assisted reaction of hydrocarbons (mostly produced by motor vehicles) with oxides of nitrogen (ARIC, 1995; British Lung Foundation, 1998). Because sunlight is required to drive production, ozone pollution is primarily a spring and summer problem, often enhanced by the presence of anticyclonic conditions promoting its build-up over a given area and subsequent trans-boundary dispersal (Her Majesty's Government, 1995; Odle et al., in prep.).

Exposure to these pollutants reduces respiratory efficiency, especially in individuals who already have a history of respiratory and cardiovascular illnesses, and leads to longer-term diseases of the respiratory tract, for example lung carcinoma and emphysema. Effects can range from increased incidences of coughs, sinusitis and shortage of breath, to asthma attacks and other episodes of impaired lung function in adults and children (Department of Health, 1995). The size and shape of a particulate are crucial in defining the type of effect it may have on health when inhaled. Larger particles (over approximately 15 microns in diameter) are normally lodged in the nose or throat and subsequently exhaled, thus never reaching the thorax (NSCA, 1995; Department of Health, 1995). Particulates with a diameter less than 4 microns can penetrate deep into the lungs and are readily deposited in the alveoli causing irritation, obstructing the air sacs and, occasionally, entering the blood stream (NSCA, 1998). There is increasing evidence that the adverse health effects of small particulates (with diameters of 2.5 microns or less) are significant, especially those particles with a diameter of less than 1.0 μm (EPAQS, 2000). Decreases in lung function, measured by changes in peak expiratory flow (PEF), due to exposure to atmospheric PM₁₀ has been shown in asthmatic and non-asthmatic individuals (Pope and Dockery, 1992; Koenig et al., 1993; Brunekreef et al., 1994; Peters et al., 1996). Similarly, effects of exposure to O₃ and to SO₂ have also been reported in asthmatics, but there is evidence that reduction in lung function of healthy individuals also occurs following exposure (Spektor et al., 1988; Krzyzanowski et al., 1992; Department of Health, 1995; AGMAPE, 1995; Rusznak et al., 1996). Exposure to nitrogen dioxide (NO₂) has been found to increase shortage of breath, colds, chronic wheezing and the prevalence of

acute respiratory disease (ARIC, 1995; British Lung Foundation, 1998). Exposure to increased levels of NO₂ and increased incidence of asthmatic episodes have been reported (Usetti et al., 1984; Weeks et al., 1995). Combinations of pollutants may promote more serious respiratory responses. Inhalation of acidic particles (for example soot) especially in combination with SO₂, has been shown to be detrimental to health (Walters et al., 1994; NSCA, 1997; British Lung Foundation, 1998), as has exposure to combinations of SO₂, NO₂ and O₃ (Devalia et al., 1994) and O₃ with NO₂ (McKee and Rodrigues, 1993).

Aeroallergens (for example pollens and spores) may trigger respiratory responses in susceptible individuals, resulting in hay fever, asthma and other episodes of irritation of the respiratory tract. There is also evidence that exposure to O₃ and to PM_{0.5} may lead to an increase in bronchial responsiveness of asthmatics to other allergens (Molfinio et al., 1991) and that pollen can act as a carrier of airborne particulate matter, which in turn may lead to increased respiratory responses in susceptible individuals (Behrendt et al., 1992). Overall, however, the combined effects of aeroallergens with other atmospheric pollutants appear to be little studied.

In order to assess the response of individuals to levels of atmospheric pollution, threshold values, known as exceedence levels, have been defined (Williams, 1997), following studies of the affects of exposure to varying levels of pollutants on health (EPAQS, 2000). Exceedences are defined on the basis of the appearance of symptoms due to exposure in individuals who are not normally sensitive.

Children are ideal subjects for the investigation of lung function and pollution. Their increased metabolic rates and normally vigorous activity means that they often have a higher exposure to airborne pollutants compared to adults in the same environment. The impact of inner city air pollution on the development of respiratory and atopic diseases in childhood is still unclear (Hirsch et al., 1999). There is evidence that exposure to some airborne pollutants reduce PEF in children (Scarlett et al., 1996; Jedrychowski et al., 1999; Marcer et al., 2000). This paper reports the results of a pilot study into the effects of airborne pollutants on the lung function of two cohorts of school children, aged 10 and 11 years, located at contrasting urban and rural sites in the south-east of England during the summer of 1998.

2. Materials and methods

Two schools, 12 km apart, participated in this study. The first was at an urban site, Luton, located in the Medway Towns, the second at a semi-rural site on the Isle of Grain, at Lower Stoke (Figure 1). The sites had continuous pollution and meteorological monitoring stations located in their grounds, operated by the South East Institute of Public Health (SEIPH). A total of 55 children participated in the study: 27 from Luton and 28 from Lower Stoke. The children attending each school lived locally to that school. Data collection commenced on 2 June at Luton and 1 June at Lower Stoke, and ran for a period of four weeks from these dates at each site. Children were aged 11 or 12 at the time of the study. Children of this age group were selected as they were of an age where they could more fully understand the reasons for the study, and link it to their schoolwork (which was also of benefit to the schools), and were in an age range where the children themselves were less likely to have started smoking.

Each child measured their peak expiratory flow (PEF) in l/min. at 9.00 BST (=UTC + 1 hour) every morning during the school day, using a Mini-Wright Peak Flow Meter. One meter was issued to each child at the start of the study and used solely by them throughout. Additionally, a questionnaire was issued to each child, asking them to provide, with parental assistance, information relating to medical history of respiratory illness, use of medication for asthma and exposure to other known respiratory irritants at home (for example cigarette smoke, gas cookers and furry animals). Because of the nature of this study, however, no confidential medical information could be requested. Although the children were instructed in the use of the flow meters and the recording of the flow data, in order to ensure that the data were collected accurately (under the supervision of a teacher) and in a consistent environment, it was decided to suspend data collection at weekends. Account was taken of these gaps in the data record in the subsequent analyses.

PEF data were obtained and analysed using standard methods (Scarlett et al., 1996; Gold et al., 1999). Each child was asked to produce three daily readings of PEF, taken sequentially. All three readings were recorded and checked using graphed expected values of PEF based on the age, height and sex of each child (Cotes, 1993). The graph gave a mean set of figures for the expected PEF measurement for children of a given range of heights. It also showed the deviation expected around these means at the 95% signifi-

cance level. Readings which were clearly impossible (i.e. beyond the physiological capability of the individual to produce) were assumed to have occurred due to errors operating the flow meters and all data recorded by that child on that day were discarded. In practice, this meant that readings of 500 l/min. or above were almost certainly inaccurate (Cotes, 1993). Following this check, the highest of three daily readings was taken as the best measure of PEF. The mean of the highest recordings was calculated throughout the study period for each child, and the daily deviation from this mean was calculated using the highest daily PEF value. The deviation (positive or negative) from the overall mean gives a measure of the lung function. By using this method of analysis, each child acts as its own control (Scarlett et al., 1996). Lung function was assessed on the basis of the percentage in the class showing sub-optimal lung function (PEF) on a given day.

Pollen was measured using a Burkard seven-day volumetric spore trap (Burkard Manufacturing Company, Rickmansworth, England), changed at 9.00 BST every Monday. Unstained slides of the daily pollen catch were prepared and daily pollen counts extracted using standard techniques (British Aerobiology Federation, 1994). Counts were measured as the number of grass pollen grains/m³ air.

Measurements of airborne particulate material (PM₁₀, μgm^{-3}), ozone (ppb) and nitrogen dioxide (ppb) were obtained from the pollution monitoring stations located in the grounds of the schools (DETR, 2001; SEIPH, 2001). Values for SO₂ were only available for one day at Luton and four days at Stoke during the study period, and were therefore not included in this study. No CO data were available at Stoke: these were also omitted from the investigation. Pollution data were obtained every 15 minutes and examined for episodes of exceedence over this period and also as hourly means, in relation to the number of children with sub-optimal lung function.

The number of children with sub-optimal PEF at each site and the daily pollen counts were compared graphically and by Spearman's Rank Correlation (r_s). These techniques were also used to compare variations in the daily pollen count between sites and the daily mean levels of the three pollutants measured at each site with the number of children showing sub-optimal lung function at that site. This was investigated on the basis of the daily measurements of PEF and also those one and two days after, to take account of any delayed effects of airborne material on lung function.

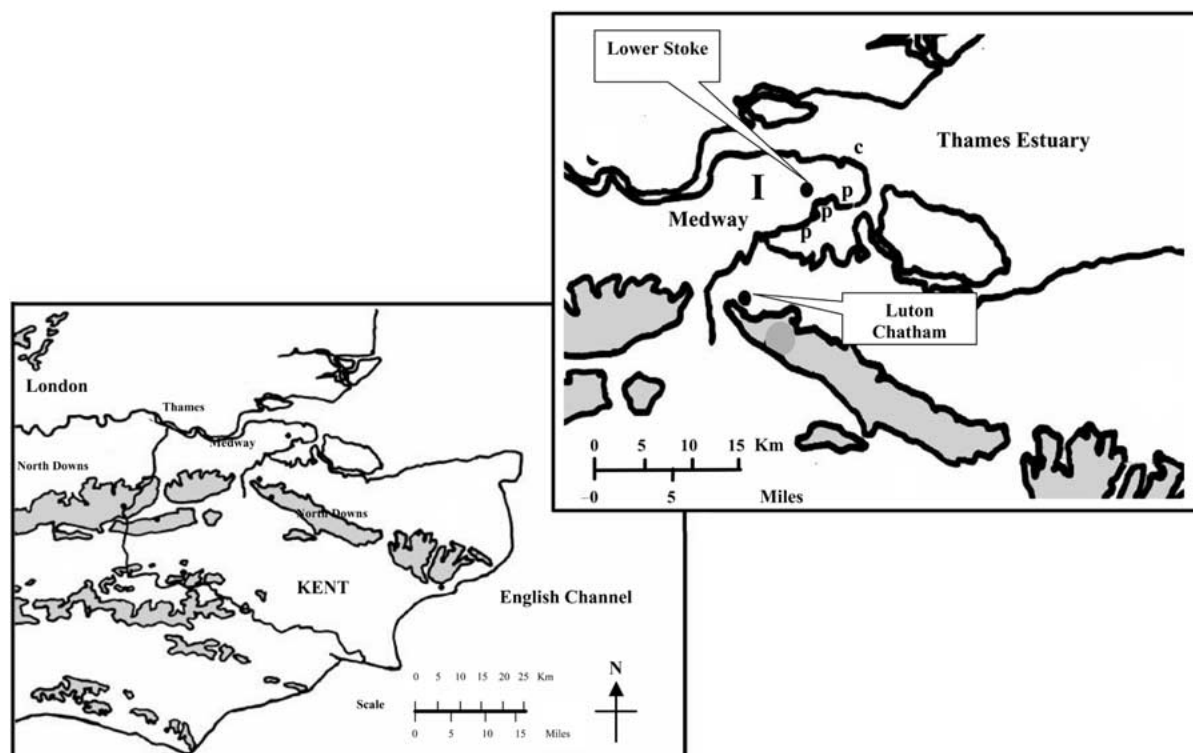


Figure 1. Map showing south-east England with the area surrounding the Medway Towns inset. The shaded areas represent land exceeding 120 metres above mean sea level. I denotes the Isle of Grain, p the positions of the 3 power stations and c the container port.

Because of problems with the weather recording equipment at both sites, weather information was obtained from synoptic charts (Deutscher Wetterdienst) and was considered on the basis of wind speed and direction and the presence of cyclonic or anti-cyclonic pressure systems which might be expected to disperse or trap pollutants, respectively. Relationships between wind speed and direction and the amount of airborne pollutants and also the number of children with sub-optimal PEF were investigated using a χ^2 test.

3. Results and discussion

3.1 Lung function data

The data from 47 children were used in the final analysis: 26 from Luton and 21 from Lower Stoke. A total of 1199 PEF readings were obtained, out of a maximum possible of 1342. No questionnaires were received from 12 children (five at Stoke and seven at Luton) and three children submitted questionnaires

with PEF measurements that were clearly unreliable. The PEF data from the five children at Stoke who did not provide questionnaire data were discarded as the measurements were also suspect. Only five children provided PEF readings for each day of the study: days were missed due to illness, holidays and unexplained absences. In addition, two further days of data were lost at Stoke due to school visits starting early in the morning (before the normal time of PEF measurement). Because of the relatively small sample size, however, all the available data have been considered.

Two children at Luton were asthmatic, and receiving medication. At Stoke, the number was seven. These children, however, could not be identified from their PEF data alone, suggesting that the asthma medication at least brought them in to the range of non-affected individuals. Accordingly, all the PEF data were considered together.

There was some suggestion of a trend in the number of children at each site showing sub-optimal lung function on a given day (Figure 2) but the readings between the two sites throughout the study period were not well correlated ($r_s = 0.37$). The proportion

of children with sub-optimal lung function at both sites was equal only once (25% on 1 July). On any given day, however, a greater proportion of the class at Stoke was more likely to show sub-optimal lung function compared to the class at Luton (17 days out of 27 at Stoke compared to 14 days at Luton). Socio-economically, the children from the two schools are from similar backgrounds, so home environments are unlikely to affect the PEF results in one cohort alone. Two other influences known to affect lung function, even in healthy individuals, are exposure to cigarette smoke and to the fumes from gas cookers. At Stoke, 62% of the children were known to have at least one smoker in the household, whilst in Luton this value was 35%; 57% of the children in the Stoke cohort had a gas cooker at home, whereas in Luton the proportion was higher (70%). There was a tendency from children at Luton to have a greater likelihood of sub-optimal PEF on any day if they were living in a household containing a smoker (Figure 3) but this trend is not consistent and requires further investigation. It is possible that the greater exposure to cigarette smoke by children at Stoke accounted for the greater likelihood of individuals in that cohort to have a sub-optimal PEF on any one day, but this cannot be resolved clearly from the data available and would also require further study. Luton is a valley site, and therefore more likely to trap aeroallergens. There is a major road running past the school at Luton, where traffic is often stationary during peak times (c. 8:30–9.00 and 16.30–17.30). In the morning, especially, children may be exposed to high levels of exhaust fumes at a time close to when the lung function measurements were taken. In contrast, the site at Stoke is relatively more industrial. Although most of the Isle of Grain is given over to farming, there are three power stations within 5 km of the school at Stoke (Figure 1) and there is a large container terminal on the coast, serviced regularly by fleets of lorries. Further work is in progress to assess the contribution of these various sources to the airborne pollution load, but the data from the present study suggest that the infrastructure around the site may be of greater influence than geography when controlling the amount of airborne material.

3.2 Lung function and pollen

Grass pollen data are only available at both sites from 15 June onwards. From this date, however, more pollen was caught at Luton rather than at Stoke,

although similar trends in the amount of pollen were observed at both sites (Figure 2). This is not surprising, given the mixed agricultural and residential environment of Stoke (the crop grown nearest to the sampling site there was potato). In contrast, the school at Luton is surrounded by houses, and their associated gardens, which would provide a rich source of grass pollen. There has been a consistent trend for more pollen to be caught at Luton for the four years since sampling at the two sites began (Burt and Sharma, unpublished data).

There was a weak positive relationship between the daily pollen count and the number of children at both sites with sub-optimal PEF ($r_s = 0.36$ and $r_s = 0.37$ for Luton and Stoke respectively), but this was not significant. Similarly, at Luton there was a weakly positive, but not significant, relationship between the number of children with sub-optimal PEF and the pollen count the day before ($r_s = 0.29$), although an extremely strong relationship was observed at this site when the pollen count two days before was considered ($r_s = 0.96$, $p = 0.001$). At Stoke there was a moderately significant relationship between the previous day's pollen count and the number of children with sub-optimal PEF ($r_s = 0.39$, $p = 0.05$), but not with regard to the pollen count two days beforehand ($r_s = 0.33$). The reason for the strong relationship between the pollen count two days before and PEF observed at Luton is not clear. The most likely cause, however, particularly in the case of measurements taken on a Monday, is a residual affect from exposure to pollen during the weekend. Pollen counts were noticeably higher on some weekends than at the start of the following week (see Figure 2, 1 June 1998 was a Monday), but PEF was not consistently low on any one day of the week, suggesting that other effects not measurable in this study (for example exposure to pollen during the weekends) were unlikely to be causing the observed pattern. The most likely explanation is that this was related to weather (see below).

3.3 Lung function and airborne pollutants

With the exception of the PM_{10} count at Stoke, there was no significant relationship ($p = 0.05$) between daily pollutant amounts and the number of children showing sub-optimal PEF at either site. There was a moderately negative ($r_s = -0.55$, $p = 0.01$) relationship at Stoke, indicating that the number of children with sub-optimal PEF increased as the amount of PM_{10} decreased. This is not what would normally be

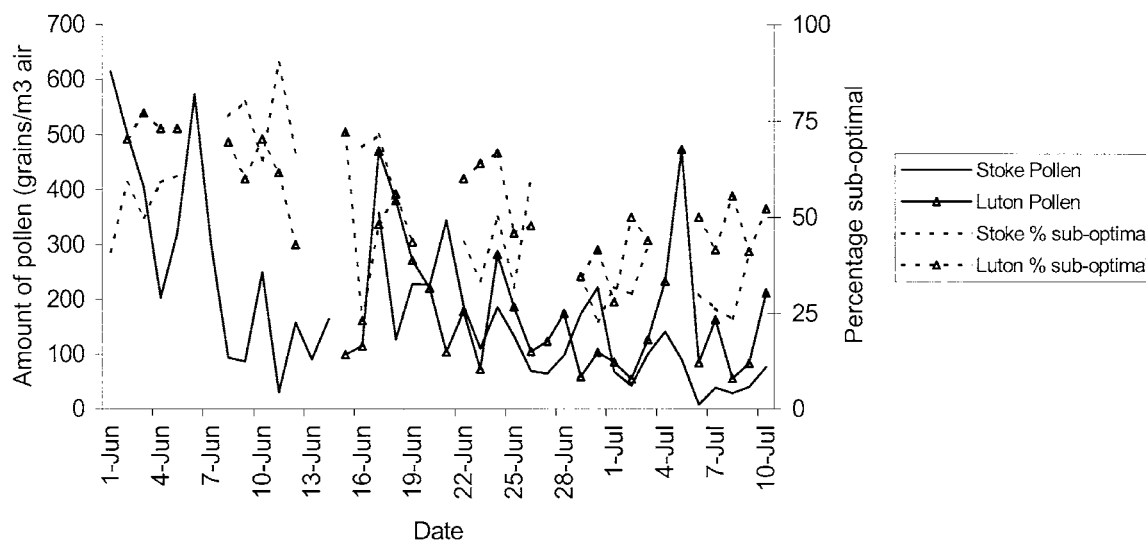


Figure 2. Relationship between number of children with sub-optimal lung function at Luton and Stoke and the amount of pollen measured at those two sites.

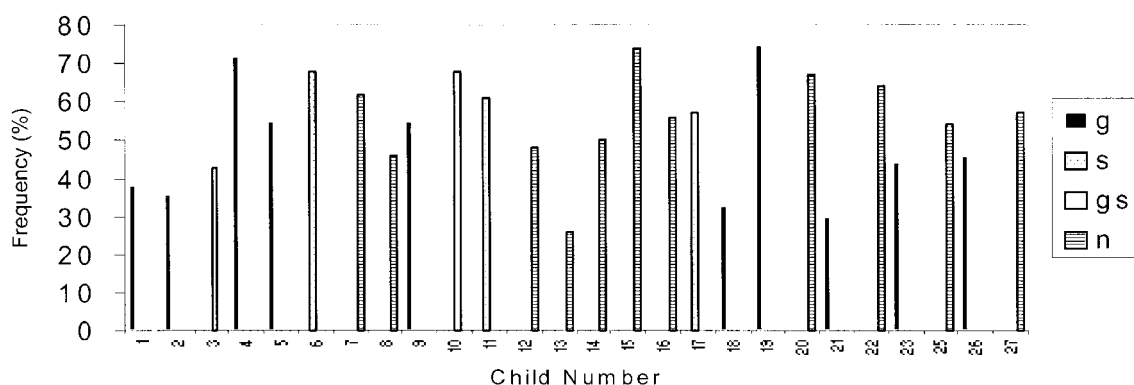


Figure 3. Frequency of sub-optimal peak expiratory flow (PEF) from children at Luton based in relation to their home environments. g denotes presence of gas cookers in the home; s at least one smoker living in the house; gs a combination of both gas cooker and at least one smoker and n none of the previous categories.

expected and reinforces the idea that other environmental conditions may be influencing lung function at Stoke, discussed in the previous section. Generally, the children at Luton showed a significant relationship ($p = 0.001$) between the number with sub-optimal PEF and the amount of all three pollutants on the day before and two days before the PEF measurements were taken. This was most pronounced for the measurements taken on the previous day ($r_s = -0.48$ for PM_{10} ; $r_s = -0.47$ for NO_2 and $r_s = -0.55$ for O_3 , $p = 0.001$). The relationship between the number showing sub-optimal PEF and pollution levels two days beforehand was similar, but inverse, for O_3 ($r_s = 0.43$, $p = 0.001$), much less pronounced in the case

of PM_{10} ($r_s = 0.16$, $p = 0.01$) and not significant for NO_2 .

There were no significant relationships between the amount of pollution the day before and the number of sub-optimal PEF measurements at Stoke, nor for two days before in the case of PM_{10} . There was a moderately positive relationship between the amount of NO_2 ($r_s = 0.4$, $p = 0.05$) and O_3 ($r_s = 0.5$, $p = 0.01$) two days before the PEF measurements were taken, suggesting that the number of children with sub-optimal lung function increases as NO_2 pollution levels increase. This is as expected from previous studies (for example Spektor et al., 1988; Krzyzanowski et al., 1992; Department of Health,

1995; Rusznak et al., 1996; Scarlett et al., 1996; Jedrychowski et al., 1999).

3.4 Lung function and weather

Throughout the study period, the most common wind direction (39% of the time) was the south-west. The axis of the Luton valley is south-east to north-west, so this direction would not promote the flushing of airborne material out of the valley on days of a south-westerly airflow. The χ^2 test showed that there was no significant relationship between wind direction and the amount of NO₂, O₃, and pollen at Luton, although the PM₁₀ level was statistically dependent on wind direction (80% significance level), as would be expected in a valley site and with regard to relatively heavy airborne material. No significant relationship was found between wind direction and the number of children with sub-optimal PEF, nor between wind speed and any of the pollutants or PEF. Similarly, no significant relationships between wind direction, wind speed, pollen or pollutants was found at Stoke. Stoke is an exposed, flat site, so no dependency on wind direction for airborne pollutant levels there is expected, although wind speed might be expected to be important as a control over dilution. Sea breezes may have a local effect on the dispersal of aeroallergens, but the detailed measurements necessary to assess their presence were not available in this study. Sea breezes, however, are less likely to be of direct influence early in the morning, when the PEF measurements were taken, although sea breezes which developed on previous days may have transported material inland. Such residual material could influence the PEF measurements. Given that sea breezes are more likely to occur under relatively stable anti-cyclonic conditions, which promote the development of such local winds, it is possible that the strong relationship between PEF and synoptic situation described below may be due in part to a sea breeze effect.

Lower pollution levels tend to be associated with cyclonic conditions, and vice versa (Henderson-Sellers, 1984; Yarnel, 1993). Consequently, it might be expected that lower PEF would be measured on days of anticyclonic conditions. The greatest number of children with sub-optimal PEF values at Stoke, however, was found on two days of cyclonic conditions (3 and 15 June, Figure 4), although anticyclonic conditions on the 4 June also produce a large number of sub-optimal PEF values. This trend was not clearly shown at Luton (Figure 2). The implied rela-

tionship between cyclonic conditions and increasing numbers of children with sub-optimal PEF at Stoke was unexpected. Weather can also affect lung function up to 48 hours after exposure (COMEAP, 1995). When the number of children with sub-optimal PEF at both sites was compared to the previous day's synoptic situation, the overall pattern was similar to that observed for the daily relationship, with some decreases in lung function at both sites on cyclonic days. Investigating lung function 48 hours after the weather condition occurred, however, suggested that the number of children with sub-optimal PEF decreased 48 hours after cyclonic conditions, with a corresponding increase after anticyclonic conditions (Figure 4 and Table 1). These observations are reinforced by the results of the χ^2 test of weather classification (cyclonic or anticyclonic) and the number of children with sub-optimal PEF. Weather classification and the number of children with sub-optimal PEF are significantly related on the day the weather system was present (70% confidence level), the day after (70% confidence level) and 48 hours after (80% confidence level). The relationship between anticyclonic weather and PEF values is not unsurprising if such conditions promote the accumulation of pollutants or aeroallergens, at both coastal sites and inland. Given this, it is probable that the sea breeze effects discussed above are of less importance in controlling local pollution dispersal than the overall synoptic situation, although calm, anticyclonic conditions in summer also promote the development of convective structures which are known to disperse material vertically and horizontally through the atmosphere (Burt, 1998). Unfortunately, the three-dimensional anemometry required to measure the presence of convective structures was not available in this study.

4. Conclusions

This study has investigated the relationship between the number of children showing sub-optimal lung function, measured as peak expiratory flow (PEF), and the presence of airborne pollutants and pollen. Data were collected from one urban, valley, site and one rural, exposed, site, 12 km apart, during the summer of 1998. More pollen was collected at the urban site than at the rural one, although trends in pollen amount were similar at both sites. On any given day, however, children at the rural site were more

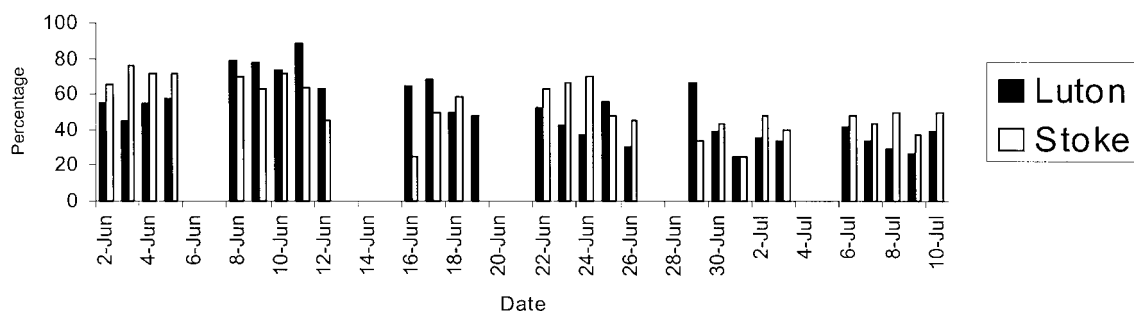


Figure 4. Comparison of the number of sub-optimal PEF measurements at Luton and Stoke (gaps due weekends and the two weekdays at Stoke when no data could be collected). Refer to Table 1 for details of synoptic weather systems present.

Table 1. Synoptic situations present over South-East England during the period 1 June to 10 July 1998.

Date	Weather system
2-3 June	Cyclonic
4 June	Anticyclonic
7 June	Cyclonic
9-10 June	Cyclonic
12	Anticyclonic
13-15 June	Cyclonic
19 June	Anticyclonic
25-28 June	Cyclonic
3-4 July	Anticyclonic

likely to have a greater incidence of sub-optimal lung function than those at the urban site. This suggests that factors other than pollen alone were influencing the PEF measurements.

There was no significant relationship between daily levels of nitrogen dioxide, ozone and the number of children showing sub-optimal PEF at either site during the study. With regard to airborne particulate material (PM_{10}), there was a moderately negative relationship at the rural site, indicating that the number of children with sub-optimal PEF increased as the amount of PM_{10} decreased. This is not what would normally be expected and further reinforces the idea that other environmental conditions may be influencing lung function. Generally, the children at the urban site showed a significant relationship between sub-optimal PEF and the amount of all three pollutants one and two days before the PEF measurements were taken. This pattern was partially reflected at the rural site, as the number of children with sub-optimal lung function increased as the amounts of nitrogen dioxide and ozone increased, with a two-day lag.

There was a significant relationship between wind direction at the urban site and the amount of PM_{10} caught, but this was not reflected in the number of children at that site with sub-optimal PEF. The generally reported relationship between cyclonic weather conditions promoting dispersal of pollutants and anticyclonic ones promoting their build up was not clearly observed in this study when considering the daily variation in PEF, although a significant, and expected, relationship was found between the weather conditions present two days before the PEF measurements were obtained.

Currently, pollen forecasts are issued on a regional basis. The variation in lung function observed in this study between children at locations which are relatively close together suggests that such regional forecasts might be masking episodes of sub-optimality and that a combination of weather and pollution factors may be more important in controlling or influencing lung function than previously thought. This may be of importance when issuing pollen or air quality forecasts, as greater attention may need to be paid to these independent measurements when considering the possible number of children (or other susceptible individuals) with episodes of respiratory distress presenting to GPs or hospitals. Further work is in progress to resolve the issues raised by the results of this investigation.

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