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Air pollution and childhood asthma emergency hospital admissions: Estimating intra-city regional variations

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Abstract
In recent years childhood asthma has increased. Although the precipitants of childhood asthma are yet to be established possible contributing factors are local ambient air pollutants. This study aims to assess associations of regional ambient air pollutants on emergency department childhood asthma presentations across four regions of the city of Melbourne, Australia. Daily emergency department (ED) presentations for asthma in children were studied for the years 2000 and 2001. Estimates of local air pollutant levels were obtained using simulation modelling techniques. Generalized Additive Models were used to examine associations between combined local levels of air pollutants and childhood asthma ED presentations adjusting for seasonal variation, day of week effects, and meteorological variables. There was consistent associations between childhood ED asthma presentations and regional concentration of PM_{10}, with a strongest association of RR = 1.17 (95% CI 1.05 to 1.31) in the central district of Melbourne. NO_2 and Ozone was associated with increased childhood asthma ED presentations in the Western districts. This study suggests that regional concentrations of PM_{10} may have a significant effect on childhood asthma morbidity. In addition, ozone may play a role however, its effect may vary by geographical region.

Keywords: *asthma, air pollution, children*

Introduction

Over the last generation in Australia childhood asthma has increased dramatically (Peat et al. 1995). This increase has also been observed in many Western countries including the USA, United Kingdom and New Zealand (Koren 1997). Coinciding with this increase has been urbanization and exposure to air pollution as citizens spend more time in traffic. Short term associations between outdoor airborne pollutants, particularly particulate matter and respiratory morbidity in adults have been well established (Hagen et al. 2000). However, very few epidemiological time series studies have been conducted in children. Studies have shown associations between increased levels of air pollutants with childhood asthma in

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Singapore (Chew et al. 1999), and Hong Kong (Wong et al. 2001), even with levels of the pollutants within the WHO-defined guidelines. Similar epidemiological time series studies have not been conducted in Australia.

Most epidemiological time series studies have assumed constant levels of air pollutants across a city (Martins et al. 2002; Galan et al. 2003; Oftedal et al. 2003) when exploring associations between air pollution and respiratory disease. The major limitation of this approach is that the chosen location may not be representative, especially if the city covers a large area, has varied topography or is subject to varied climatic conditions (e.g. sea breezes). It is possible that there is considerable variation in local concentrations of pollutants and their impact on health. Studies suggest that both symptoms and hospital admissions in asthmatic children vary between urban and rural settings (Lewis et al. 1997; Duran-Tauleria and Rona 1999) but intra-city variation has not been explored.

The objectives of this study are to estimate the health effects of air pollution on childhood emergency department (ED) asthma presentations in Melbourne, Australia and to determine if there is an association between local concentration of air pollutants and ED childhood asthma presentations.

Methods

Setting

Melbourne is a coastal city situated on Port Phillip Bay with ocean to the south and hills to the north. Its population of 3.4 million is spread over 1700 km^2 around the bay and into the foothills of the ranges in the north-east. Motor vehicles are the major source of pollution, though road dust (43%) and wood heaters in winter (28%) contribute substantially to PM_{10} emissions. NO_2 and O_3 are secondary pollutants that form from volatile organic compounds (VOCs) and nitrogen oxides (NO_x) in the presence of sunlight and high temperatures. In the summer, morning vehicle emissions drift over Port Phillip Bay, forming ozone that is transported back over the city and suburbs by the afternoon sea breeze.

Hospital admissions data

Daily childhood hospital ED presentation data from six public hospitals (see Figure 1) represent four distinct regions—Sunshine Hospital in the west of the city, Royal Children's Hospital located centrally, Frankston Hospital in the south east on the bay shore and Box Hill, Maroondah and Angliss Hospitals (treated as a single group) in the east towards the ranges.

The source population comprised children aged between 1 and 15 years for the period of January 2000 to December 2001 with an ED diagnosis of asthma (ICD10 codes J45, J46) matched to the child's post code of residence. Children aged less than 1 year were excluded to avoid overlap with bronchiolitis. Children residing outside the geographical areas covered by these hospitals were excluded to maximise the validity of calculated air pollutant and meteorological exposure (see below).

Air pollution and meteorological data

Air pollution and meteorological variables were obtained from an air quality simulation model (TAPM) developed by CSIRO Atmospheric Research (Hurley 2002). TAPM predicts gridded fields of meteorology and ground-level concentration for various pollutants, and has been validated for a number of data sets and regions (Hurley at al. 2002), including

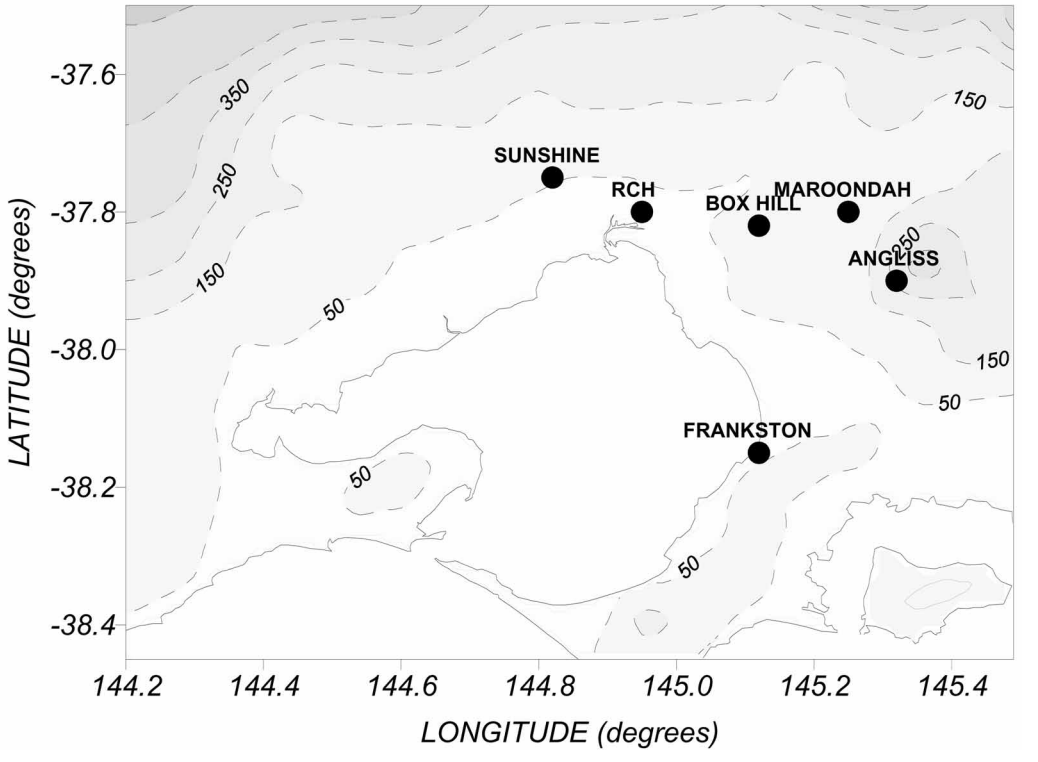

Figure 1. Study hospital distribution. Sunshine Hospital represents the western region, Royal Children's Hospital [RCH] the inner city region, Frankston Hospital the south east and the group of Box Hill, Angliss and Maroondah Hospitals the eastern region.

Melbourne (Hurley et al. 2003). It has also been used in a study with the Environment Protection Authority of Victoria to determine air pollutant concentrations in the greater Melbourne under future emission scenarios for 2008 and 2021 (Hurley et al. 2001).

TAPM was run for the two years of the study (2000 and 2001), producing hourly-averaged concentrations of NO_2, O_3 and PM_{10} on a 1-km spaced grid within Melbourne. From this data set, a representative daily value for each of the four regions; Western, Inner Melbourne, South/South Eastern and Eastern was obtained by selecting the maximum hourly value over 24 h at each gridpoint and then taking a mean value over those postcodes in the region that provided presentations. This regional daily value for each pollutant was assigned to the daily ED presentations.

Statistical methods

Generalized Additive Models (GAM) were used to describe associations between ambient levels of air pollutants, meteorological variables and childhood ED asthma presentations. Log link was assumed and quasilikelihood estimation used to account for the over-dispersion inherent in data of this nature. GAMs fit a nonparametric smooth curve to each of the pollutant and meteorological variables adjusting for other potential confounders in the analysis. The pollutant—ED presentation and meteorological variables—ED presentation curves are presented as a cubic smoothing spline (Simonoff 1996) on a partial residual scale,

adjusting for significant covariates with corresponding 95% confidence intervals. Akaike's Information Criterion, (AIC) (Akaike 1973) is used to evaluate each model.

To control for the presence of long wave-length patterns in the outcome variable, trigonometric pairs of sine and cosine terms up to k = 8 were fitted. Sine and cosine pairs where at least one of them are statistically significant were included to contribute to filtering out the long wave-length patterns in the residuals of the base model. The day of week effect was explored using a parameterization based on Helmert contrasts (Venables and Ripley 1994), with Sunday as the reference day. An exploratory analysis of daily childhood asthma ED presentations and the study period suggest a nonlinear pattern. Smoothing splines were used to capture the non-linear time (days) trend.

After identifying the base model for each pollutant and meteorological variable, instantaneous lags of up to 2 days were fitted. Co-plots (Erbas and Hyndman 2001) were used to investigate possible interactive effects between combinations of pollutants and meteorological variables on the outcome. An autocorrelation plot of the residuals for the regression models for each region will show any remaining autocorrelation that needs to be identified. If autocorrelation was present in the residuals, Generalized Estimating Equations (GEE's) with autoregressive error terms were fitted.

Results

A total of 8955 childhood ED asthma presentations were analysed from all regions over the period from January 1, 2000 to December 31, 2001. The mean number of daily childhood asthma ED presentations per day was 3.06 (standard deviation 2.49), ranging from a mean 1.13 to 4.54 in each region (Table I). The fluctuations in asthma ED presentations in each region for the study period are displayed in Figure 2. The seasonal variation is very similar for the Western, Inner Melbourne, and Eastern regions, with high admissions occurring in autumn and spring and lower admissions in winter and summer. The South/South Eastern region shows this pattern also, but with less variation than the other three regions.

Table II shows summary statistics for hourly levels of air pollutants and meteorological variables. The hourly mean concentrations of ozone showed only minor regional variations whereas, both the mean hourly PM_{10} and NO_2 concentrations were highest in the inner Melbourne region (34×10^{-6} m/g^3 and 19 ppb respectively).

Table III displays the Relative Risks and 95% Confidence Intervals of childhood ED asthma presentations for each region in Melbourne, Victoria for an increase from the 10th to 90th centile of levels of pollutants fitted as linear components in the GAM. PM_{10} had the strongest association in Inner Melbourne RR = 1.17, 95% CI 1.05 to 1.31 ($P = 0.01$) (for an increase from the 10th to 90th centile) with a modest association in the Eastern district RR = 1.09 (95% CI 1.01 to 1.18; $P = 0.03$). NO_2 had negative effects in Inner Melbourne

Table I. Summary measures (mean, SD = standard deviation, median, minimum, and maximum) of daily childhood asthma emergency presentations for each region in Melbourne, Victoria, 2000 to 2001.

District	Mean (SD)	Median	Minimum	Maximum
Western	2.99 (2.11)	3	0	11
Inner Melbourne	4.54 (2.65)	4	0	17
South/South Eastern	1.13 (1.18)	1	0	6
Eastern	3.61 (2.39)	3	0	16
Total[a]	3.06 (2.49)	3	0	17

[a]Represents summary statistics for the four regions combined.

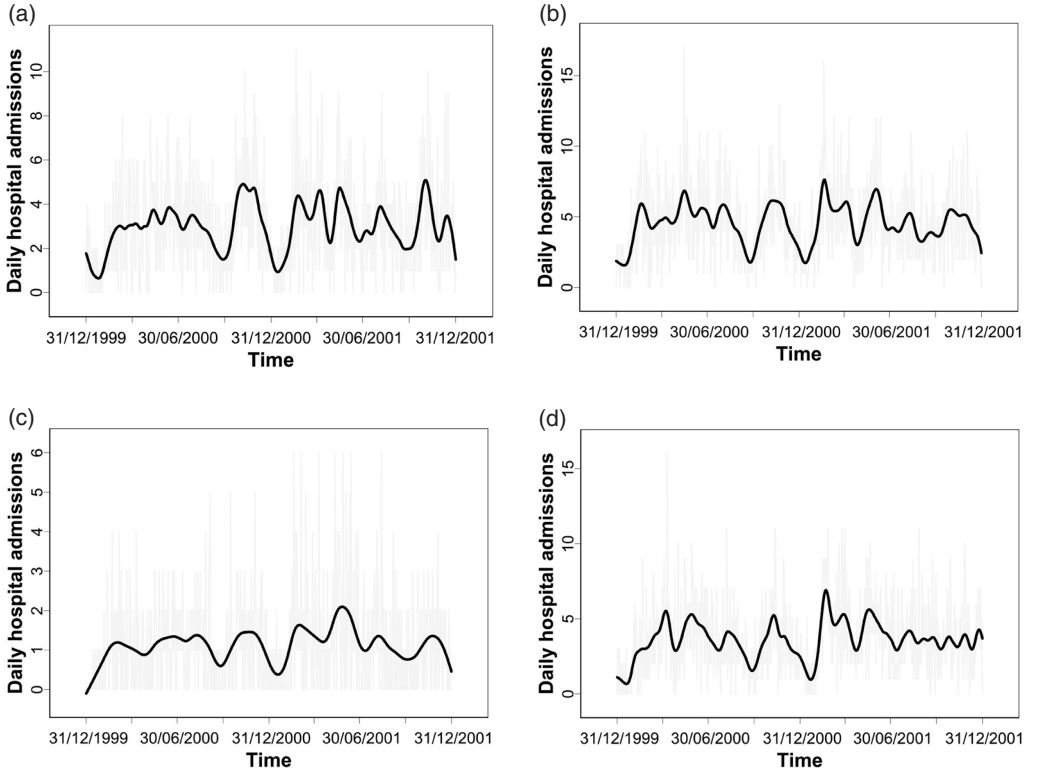

Figure 2. A smooth cubic spline superimposed on daily childhood asthma emergency presentations (y-axis) for each of region (A) Western district, (B) Inner Melbourne district, (C) South/South Eastern district, (D) Eastern district from 2000 to 2001. The scale of the y-axis differs across each region to reflect variation in number of emergency presentations for each region.

RR = 0.83 (95% CI 0.68 to 0.98; $P = 0.02$). However, a positive 2-day lag effect of NO_2 was observed in the Western district RR = 1.15 (95% CI 1.03 to 1.27; $P = 0.02$). No significant linear associations were found between ozone and childhood ED asthma presentations.

Regional PM_{10}, NO_2 and Ozone – childhood ED asthma presentation nonparametric curves are shown in Figure 3. These curves were estimated using cubic smoothing splines. The PM_{10} curve for the western district indicates some departure from linearity. There is evidence of a levelling of hospital presentations at higher values of PM_{10}. Levels of lag 1 day PM_{10} in the Inner Melbourne district also indicates moderate departure from linearity (data not shown for regional lag effects).

The Western and South/South Eastern districts exhibit a decrease in childhood ED asthma presentations with lower levels of same day NO_2 (< 40 ppb for the Western and < 15 ppb for the South/South Eastern district) and a modest increase with extreme levels of same day NO_2 (> 45 ppb for the Western and > 20 ppb for the South/South Eastern district). Levels of lag 2 NO_2 are also associated with childhood ED asthma presentations in the South/South Eastern district (data not shown). Evidence in the Western and South/South East district indicates an increase in childhood ED asthma presentations at all levels of same day ozone.

For each region analysis, the final multi-pollutant model adequately captures associations between air pollutants and childhood asthma emergency presentations in the absence of autocorrelation.

Table II. Means, standard deviations, 10th and 90th centile of daily air pollutants and meteorological variables assigned to ED presentations for each region in Melbourne, Victoria, 2000 to 2001.

District	Western	Inner Melbourne	South/South Eastern	Eastern	Spatial mean
PM_{10} ($10^{-6}g/m^3$) – 1 h					
Mean	26.47	33.71	21.22	30.55	30.07
Standard deviation	15.01	20.17	11.27	17.65	15.27
Minimum	9.00	10.89	6.13	9.00	10.55
10th centile	13.67	15.63	12.00	16.00	16.00
90th centile	48.00	59.73	36.05	51.05	50.51
Maximum	94.33	174.67	84.50	183.67	112.33
NO_2 (ppb) – 1 h					
Mean	17.04	18.60	12.73	15.64	16.80
Standard deviation	11.49	10.71	6.97	7.34	8.61
Minimum	1.00	1.00	0.00	0.50	2.43
10th centile	5.00	7.56	4.00	7.48	7.48
90th centile	33.86	33.00	21.74	25.15	29.37
Maximum	70.00	72.67	50.00	54.00	63.00
O_3 (ppb) – 1 h					
Mean	22.35	21.89	21.90	22.53	22.33
Standard deviation	11.44	10.81	10.66	10.91	10.62
Minimum	6.00	5.25	6.13	6.80	8.00
10th centile	14.00	13.50	12.98	13.50	13.75
90th centile	37.77	36.03	37.52	37.35	36.80
Maximum	75.33	70.50	81.00	72.60	69.57
Maximum temperature					
Mean	20.39	20.39	19.03	20.39	20.39
Standard deviation	6.39	6.39	6.39	6.39	6.39
Minimum	9.00	9.00	6.13	9.00	9.00
10th centile	13.69	13.69	12.42	13.70	13.69
90th centile	29.60	29.60	28.81	29.60	29.60
Maximum	42.20	42.20	42.20	42.20	42.20
Minimum temperature					
Mean	10.40	10.40	10.86	10.41	10.40
Standard deviation	3.11	3.11	3.40	3.10	3.11
Minimum	5.00	5.00	5.00	5.00	5.00
10th centile	7.00	7.00	7.00	7.00	7.00
90th centile	15.00	15.00	15.38	15.00	15.00
Maximum	22.00	22.00	26.71	22.00	22.00
Maximum Humidity					
Mean	12.80	12.79	12.78	12.80	12.80
Standard deviation	6.36	6.36	5.90	6.35	6.36
Minimum	4.82	4.82	4.84	4.82	4.82
10th centile	7.20	7.20	7.36	7.22	7.20
90th centile	20.66	20.66	19.61	20.66	20.66
Maximum	45.09	45.09	45.09	45.09	45.09
Minimum Humidity					
Mean	2.71	2.71	4.58	2.71	2.71
Standard deviation	1.15	1.15	4.51	1.15	1.15
Minimum	0.00	0.00	0.00	0.00	0.00
10th centile	1.00	1.00	1.00	1.00	1.00
90th centile	4.00	4.00	12.46	4.00	4.00
Maximum	7.00	7.00	26.71	7.00	7.00

Table III. Relative Risk and 95% CI of childhood asthma emergency presentations for each region in Melbourne, Victoria for an increase from the 10th to 90th centile of levels of pollutants, entered as linear components in a Generalized Additive Model. Lags are 0, 1 or 2 days.

Pollutant	Single day lag	Relative risk (95% CI)	*P* value
Western			
PM_{10}	0	$S(PM_{10})$	0.008
NO_2	0	$S(NO_2)$	0.006
	1	1.02 (0.88 to 1.16)	0.8
	2	1.15 (1.03 to 1.27)	0.02
O_3	0	$S(O_3)$	0.05
Inner Melbourne			
PM_{10}	0	1.17 (1.05 to 1.31)	0.01
	1	$S(PM_{10,\ t-1})$	0.04
NO_2	0	0.83 (0.68 to 0.98)	0.02
O_3	0	1.00 (0.89 to 1.12)	0.9
South/South Eastern			
PM_{10}	0	1.14 (0.95 to 1.33)	0.2
NO_2	0	$S(NO_2)$	0.001
	1	0.98 (0.79 to 1.18)	0.9
	2	$S(NO_{2,\ t-2})$	0.006
O_3	0	$S(O_3)$	0.01
Eastern			
PM^{10}	0	1.09 (1.01 to 1.18)	0.03
NO_2	0	1.07 (0.93 to 1.22)	0.4
O_3	0	0.92 (0.79 to 1.05)	0.2

S(single day lag pollutant): smooth cubic polynomial fit.

Discussion

To date most studies have focused on combined city-specific analysis, with the exception of a few recent studies (Samoli et al. 2001; Dominici et al. 2002). There has been no study that has focused on intra-city regional variations in associations between combined effects of pollutants and childhood ED asthma presentations. In this large region-specific analysis consistent effects of local PM_{10} concentrations across regions and regional variation in the effects of ozone on childhood ED asthma presentations have been observed.

Evidence of deviations from linearity of PM_{10}, NO_2 and ozone was found in the Western district, lag 1 day PM_{10} levels in Inner Melbourne, and same day, lag 2 day NO_2 and ozone in the South/South Eastern district. These results suggest that combinations of pollutants are associated with childhood emergency presentations, and reinforce the hypothesis that air pollution, in particular PM_{10}, is associated with respiratory morbidity in children.

In this study, results on the adverse effects of PM_{10} at levels below the WHO guidelines on childhood ED asthma presentations are consistent with other epidemiological time series studies of childhood ED asthma presentations (Chew et al. 1999; Thompson et al. 2001). Although in this study the focus is on ED presentations, the adverse effects of PM_{10} have also been observed in hospital admissions in asthmatic children (Wong et al. 2001).

Findings on the effects of ozone are not in agreement with other studies of ED presentations for childhood asthma (Garty et al. 1998; Chew et al. 1999). In this study possible non-linear pollutant effects were investigated using Generalized Additive Linear Models, suggesting that same day ozone to be significantly associated with childhood asthma ED presentations in both the Western and South/South Eastern districts. Recently, two studies report no association between ozone and childhood asthma hospital presentations

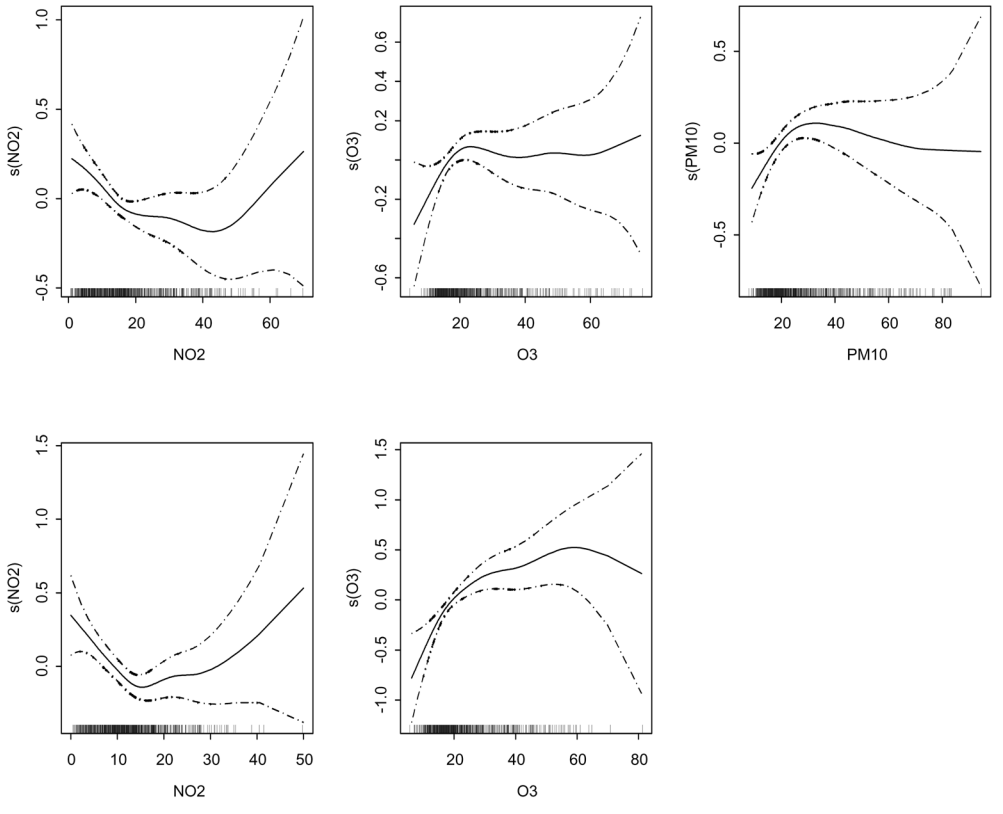

Figure 3. Non-linear functions for daily levels of pollutants and meteorological variables in the Generalized Additive Model for childhood asthma emergency presentations. The fitted curve represents a cubic smoothing spline fit on the partial residual scale (y-axis) for levels of pollutants (x-axis). Dashed lines represent point-wise 95% confidence intervals. The first row represents smooth curves for Western district; the second row represents curves for South/South Eastern district (Lag effects not shown).

(Chew et al. 1999; Thompson et al. 2001). They however use statistical methods that are unable to capture non-linear relationships, which may explain the inconsistencies in findings of ozone.

In this study the effects of same day and lagged NO_2 showed mixed results. The negative linear effect of NO_2 maybe acting as a surrogate for a mixture of other pollutants not included in this study such as sulphur dioxide [SO_2]. The covarying effects of SO_2 on other pollutants have been documented elsewhere (Schwartz et al. 1994). However, the concentrations of SO_2 in many countries including Australia are much lower than recommended guidelines and thus were not included in this study. Recently, a large European study of the effects of pollution on both childhood and adult respiratory emergency visits (Sunyer et al. 1997) found same day and lagged 1 day levels of NO_2 were negatively associated (although not significant) with childhood and adult emergency visits in a number of European countries—a similar finding to that in this study.

It is possible that pollen is a significant contributor to childhood ED asthma presentations. Unfortunately, data on daily levels of pollen were not available for inclusion in this study. The combined effects of gaseous pollutants and respirable particulate matter including pollen may exacerbate symptoms in already allergic subjects and can induce symptoms in predisposed

subjects (Lebowitz 1996). It is known that most children with asthma are atopic to common aeroallergens including grass pollens (Riedinger et al. 2002). It has also been suggested that pollen grains are a good indicator with which to investigate independent and joint adverse effects between air pollutants on respiratory allergic diseases because of their inter-relationships with meteorological factors (Knox et al. 1997). The role played by pollen in acute childhood respiratory disease is yet to be clarified.

All districts other than south/south eastern showed consistent adverse effects of PM_{10}. The south/south eastern district is suburban but not densely populated (semi-rural) with much less traffic and industry than the other regions. It is also located on the bay and thus subject to sea breeze related effects. These differences may go some way to explain the different associations found for this district.

The findings from this study raise some questions for further research and for public health-town planning. Clearly the role of pollen and its interactions with the other pollutants including SO_2 is worthy of further exploration. Data from this study, combined with the other related evidence, suggests that reducing PM_{10} levels might improve asthma morbidity for children with asthma. How this is done is a matter for public health planners. It also suggests that days with high PM_{10} levels place added strain on hospital EDs. Given the sophisticated modelling techniques available, these days may be able to be predicted and additional resources allocated.

A number of limitations should be considered when interpreting the results. It relies on coding data, so cases with incorrect coding would be missed. This should not introduce a systematic bias. The study focuses on ED asthma presentations that are only a proportion of asthma morbidity as most mild to moderate exacerbations are managed by families and general practitioners. That said ED presentations are probably a reasonable indication of moderate to severe morbidity for this group of patients.

Conclusion

In summary, these findings suggest a consistent positive association with ambient levels of PM_{10} on childhood asthma ED presentations. Possible local variations in ambient levels of ozone may also have contributed to intra-city variations in associations with childhood asthma ED presentations.

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References

Akaike H. 1973. Information theory & an extension of the maximum likelihood principle. In: Petrov BN, Csaki F, editors. 2nd International Symposium on Information Theory. Budapest: Adademiai Kidao; pp. 267–281.

Chew FT, Goh DYT, Ooi BC, et al. 1999. Association of ambient air pollution levels with acute asthma exacerbation among children in Singapore. Allergy 54:320–329.

Dominici F, Daniels M, Zeger S, et al. 2002. Air pollution and mortality: Estimating regional and national dose-response relationships. J Amer Stat Assoc 97:100–111.

Duran-Tauleria E, Rona RJ. 1999. Geographical and socioeconomic variation in the prevalence of asthma symptoms in English and Scottish children. Thorax 54:476–481.

Erbas B, Hyndman R. 2001. Data visualisation for time series in environmental epidemiology. J Epidemiol Biostat 6:433–443.

Galan I, Tobias A, Banegas JR, et al. 2003. Short-term effects of air pollution on daily asthma emergency room admissions. Eur Respir J 22:802–808.

Garty BZ, Kosman E, Ganor E, et al. 1998. Emergency room visits of asthmatic children, relation to air pollution, weather, and airborne allergens. Ann Allergy Asthma Immunol 81:563–570.

Hagen JA, Nafstad P, Skrondal A, et al. 2000. Associations between outdoor air pollutants and hospitalization for respiratory diseases. Epidemiology 11:137–140.

Hurley P. 2002. The air pollution model version 2, part 1: Technical description. CSIRO Atmospheric Research, Technical paper No. 55.

Hurley PJ, Physick WL, Luhar AK. 2002. The air pollution model (TAPM) version 2, part 2: Summary of some verification studies. CSIRO Atmospheric Research, Technical paper No. 57.

Hurley P, Manins P, Lee S, et al. 2003. Year-long, hi-resolution, urban airshed modelling: Verification of TAPM predictions of smog and particles in Melbourne, Australia. Atmos Environ 37:1899–1910.

Hurley P, Manins P, Lee S. 2001. Year-long air pollution modelling using TAPM for the EPAV Air Quality Improvement Plan. CSIRO Atmospheric Research, Report to the Environment Protection Authority of Victoria for the Air Quality Improvement Plan.

Knox RB, Suphioglu C, Taylor P, et al. 1997. Major grass pollen allergen Lol p 1 binds to diesel exhaust particles: implications for asthma and air pollution. Clin Exp Allergy 27:246–251.

Koren HS. 1997. Environmental risk factors in atopic asthma. Int Arch Allergy Immunol 113:65–68.

Lebowitz MD. 1996. Epidemiological studies of the respiratory effects of air pollution. Eur Respir J 9:1029–1054 Review.

Lewis S, Hales S, Slater T, et al. 1997. Geographical variation in the prevalence of asthma symptoms in New Zealand. NZ Med J 110:286–289.

Martins LC, Latorre Mdo R, Saldiva PH. 2002. Air pollution and emergency room visits due to chronic lower respiratory diseases in the elderly: an ecological time-series study in Sao Paulo, Brazil. J Occup Environ Med 44:622–627.

Oftedal B, Nafstad P, Magnus P, et al. 2003. Traffic related air pollution and acute hospital admission for respiratory diseases in Drammen, Norway 1995–2000. Eur J Epidemiol 18:671–675.

Peat JK, Toelle BG, Gray EJ, et al. 1995. Prevalence and severity of childhood asthma and allergic sensitisation in seven climatic regions of New South Wales. Med J Aust 163:22–26.

Riedinger F, Kuehr J, Strauch E, et al. 2002. Natural history of hay fever and pollen sensitization, and doctors' diagnosis of hay fever and pollen asthma in German schoolchildren. Allergy 57:488–492.

Samoli E, Schwartz J, Wojtyniak B, et al. 2001. Investigating regional differences in short-term effects of air pollution on daily mortality in the APHEA project: a sensitivity analysis for controlling long-term trends and seasonality. Environ Health Perspect 109:349–353.

Schwartz J, Dockery DW, Neas LM, et al. 1994. Acute effects of summer air pollution on respiratory symptom reporting in children. Am J Respir Crit Care Med 150:1234–1242.

Simonoff JS. 1996. Smoothing methods in statistics. New York: Springer.

Sunyer J, Spix C, Quenel P, et al. 1997. Urban air pollution and emergency admissions for asthma in four European cities: the APHEA Project. Thorax 52:760–765.

Thompson AJ, Shields MD, Patterson CC. 2001. Acute asthma exacerbations and air pollutants in children living in Belfast, Northern Ireland. Arch Environ Health 56:234–241.

Venables WN, Ripley BD. 1994. Modern applied statistics with S-plus. 2nd ed. New York: Springer-Verlag.

Wong GWK, Ko FWS, Lau TS, et al. 2001. Temporal relationship between air pollution and hospital admissions for asthmatic children in Hong Kong. Clin Exp Allergy 31:565–569.