A case-crossover analysis of traffic-related air pollution and emergency department presentations for asthma in Perth, Western Australia

Gavin Pereira, Angus Cook, Annemarie JBM De Vos and C D'Arcy J Holman

ABSTRACT

Objective: To determine whether changes in 24-hour average background ozone (O_3), nitrogen dioxide (NO_2), carbon monoxide (CO) and particulates < 10 μm (PM_{10}) increase the risk of hospital emergency department (ED) presentations for asthma among children.

Design, setting and subjects: A time-stratified case-crossover method was used to analyse data of 603 children and young adults aged 0–19 years who were resident in a south-west metropolitan area of Perth, Western Australia, and who had presented with asthma at any public ED within Perth between 1 January 2002 and 31 December 2006. Effect sizes were assessed in relation to age group, sex and season of exposure. City-wide background air pollution was estimated from air monitoring network data.

Main outcome measures: ED presentation with asthma.

Results: Patients 0–4 years with 1-day lagged exposure to NO_2 and CO showed the most significant risk of ED presentation for asthma. An interquartile range (IQR) increase in NO_2 resulted in an odds ratio (OR) of 1.70 (95% CI, 1.08–2.69). An IQR increase in CO resulted in an OR of 1.40 (95% CI, 1.06–1.84).

Conclusions: The effect sizes observed in this study were higher than those of past studies, and indicated that children aged 0–4 years were the most vulnerable to the effects of air pollution. The period of exposure most clinically relevant is the day before ED presentation.

MJA 2010; 193: 511–514

Recent studies have reported significant associations between air pollution and the exacerbation of asthma.[1-4] Traffic-related air pollution, the largest anthropogenic contributor to ambient air pollution in many cities, has been particularly implicated.[5,6] However, the strength of the effect of air pollution on asthma exacerbation resulting in use of hospital services has not yet been adequately assessed.

Various studies have measured hospital admissions rather than emergency department (ED) presentations.[1,7-12] Patients experiencing milder asthmatic symptoms are under-represented in such studies because 60% of patients who present at an ED with asthma show "mild" symptoms and only 13% of these patients are subsequently admitted.[13] ED presentations are also of interest in relation to health service use given the typically high workloads and time-critical responsibilities of ED staff.

A common method for estimating background pollution is to average the concentrations obtained from a set of monitoring sites. However, this estimate is more accurate for patients living close to monitoring sites, and may be biased by the higher records from monitors positioned in "problem spots".[14] An alternative approach based on modelling exposure using monitored pollutant concentrations has potential to overcome these problems,[15] and was adopted for our study.

In Australia, research on the relation between asthma ED presentation and ambient air pollution is limited, although a 2005 study conducted in Sydney reported significant associations with all criteria pollutants examined, despite the generally low levels of ambient air pollution.[16] We were motivated by these results to determine whether such associations are to be found in the city of Perth, Western Australia, whose airshed is characterised by different pollutant mixtures and meteorological conditions.

METHODS

Study design and rationale

A record-based, time-stratified case-crossover method was used.

Studies of the impacts on health of air pollution often involve time-series designs, many of which are prone to seasonal or other temporal confounding effects, including those that pertain to the patient. These can be minimised by the use of a case-crossover design, which inherently controls for both measured and unmeasured time-invariant confounders (eg, socioeconomic position) including those that slowly vary with respect to the reference time-period window.[17] The case-crossover design achieves this by comparing the patient's exposure directly before an ED presentation to their exposure at other times when they did not present at an ED. For example, the design can control for socioeconomic position because this is unlikely to change within a relatively short reference time period (eg, a calendar month, as in our study). By comparing exposure preceding the ED presentation with exposure on days shortly before and after the ED presentation, one can also remove effects associated with seasonal trends. Other examples of patients' risk factors and study confounders that can be controlled for under this design are body mass index, diet, seasonal comorbidities and exposure to pollen, environmental tobacco smoke and indoor allergens.

Study area

The study area included 613 census collection districts (CDs), within south-west metropolitan Perth. CDs are geographical areas for which demographic statistics are disseminated by the Australian Bureau of Statistics, and each on average included 225 dwellings. Perth is protected from air pollution entering from other urban airsheds by its location on a coastal plain between the Indian Ocean to the west and the 300–400 m-high Darling escarpment to the east.[18] It is also more than 2000 km from the nearest major city. Perth's south-western area was selected because it is traversed by both major metropolitan vehicle corridors and quieter local roads; it is geographically isolated from major industrial sources of air pollution; and its population has a wide socioeconomic range. The total population in the area was 269 734.

Data collection

Data were collected from WA Department of Health records on patients aged 0–19 years, living in the study area, who had presented at any of the nine public hospital EDs within Perth between 1 January 2002 and 31 December 2006 and had been assigned a principal diagnosis of asthma (International classification of diseases, 10th revision [ICD-10]: J45) or status asthmaticus (ICD-10: J46). Seven different patient exposure periods were investigated for all patients: 0, 1, 2, 3, 0–1, 0–2, and 0–3 days prior to the ED visit. Each patient's exposure day was matched to a set of referent control exposure days for the same patient falling on the same day of the week, in the same calendar month, in the same year as the day of the ED presentation.

Exposure assessment

To obtain a city-wide pollutant concentration for each day, a model for the background pollutant was used.[15]

Daily 24-hour average concentrations of particulates < 10 μm (PM_{10} [μg/m^3]), ozone (O_3 in parts per billion [ppb]), nitrogen dioxide (NO_2 in ppb) and carbon monoxide (CO in parts per million [ppm]), along with meteorological data (wind speed, wind direction and temperature), were obtained from the WA Department of Environment and Conservation for 10 monitoring sites for the 8-year period beginning 1 January 2000 and ending 31 December 2007. A separate regression model was developed for each air-monitoring station's pollutants using a temporal seasonal predictor (defined using spectral analysis) and a meteorological predictor (using temperature, wind speed and wind direction). Only statistically significant predictors at the 5% level were retained. The independent variables that were common to all regression equations were used as independent variables in the final model for background air pollution. Validation was performed by using Pearson correlations to compare the modelled daily concentrations with those derived from averaging across all monitoring stations. Correlations were observed to be high over the study period for CO (0.783); NO_2 (0.780); and O_3 (0.715); the correlation was lower for PM_{10} (0.486).

Statistical analyses

Case-crossover analyses were performed using conditional logistic regression, which was implemented with the proportional hazards (TPHREG) procedure in the software package SAS, version 9.1 (SAS Institute Inc, Cary, NC, USA). A 2-week exclusion period was constructed by removing from analyses patients who had experienced multiple ED presentations within their control period. Patients who re-presented during their reference period were also removed from the analyses. Analyses were subsequently stratified by sex and age group for lag periods where an elevated risk was observed. Due to the difference in lung function across the ages of the study population, age was initially grouped into four equal bands for analyses but later grouped into three bands (ie, 0–4, 5–9 and 10–19 years) to better accommodate the sample size.

1 Characteristics and times of ED visits of children and young adults of south-west metropolitan Perth, Western Australia, who were diagnosed with asthma on ED presentation, 1 January 2002 to 31 December 2006

	Patients (%) *n* = 603
Sex	
Male	341 (57%)
Female	262 (43%)
Age	
0–4 years	224 (37%)
5–9 years	176 (29%)
10–14 years	112 (19%)
15–19 years	91 (15%)
Season of ED visit	
Summer	110 (18%)
Autumn	172 (29%)
Winter	192 (32%)
Spring	129 (21%)
Day of ED visit	
Sunday	112 (19%)
Monday	88 (15%)
Tuesday	82 (14%)
Wednesday	86 (14%)
Thursday	82 (14%)
Friday	71 (12%)
Saturday	82 (14%)
Maternal ethnicity	
Non-indigenous	563 (93%)
Indigenous	40 (7%)
SEIFA quintile	**SEIFA range***
1	< 970
2	970–1028
3	1029–1065
4	1066–1095
5	> 1095

ED = emergency department. SEIFA = socio-economic indexes for areas. * SEIFA range shows study area's socioeconomic status (40th percentile, 1028) to be slightly higher than the Australian mean (1000). ◆

Ethics

Ethics approval was obtained from the University of Western Australia Human Research Ethics Committee and the Department of Health Western Australia Human Research Ethics Committee.

RESULTS

Demographics

Between 2002 and 2006, there were 603 children and young adults aged up to 19 years who were resident in the study area and had presented at a Perth ED with a primary diagnosis of asthma (Box 1). Most of the children were boys (57% [341]); under the age of 10 (66% [400]); and presented at the ED on Sundays (19% [112]) and in autumn or winter (60% [364]). Forty children (7%) were classified as Indigenous. The socioeconomic index for areas (SEIFA) has a mean of 1000 (SD 100) across Australia. Relative to this distribution, the study area was of slightly higher socioeconomic status, with the 40th percentile (1028) being higher than the Australian mean.

Air pollutant concentrations

The 25th percentile (P_{25}) and 75th percentile (P_{75}) of the observed 24-hour pollutant concentrations at the nearest monitoring station (South Lake) over the study period were: 5 ppb (P_{25}) and 10 ppb (P_{75}) for NO_2; 0.1 ppm (P_{25}) and 0.3 ppm (P_{75}) for CO; 13 μg/m^3 (P_{25}) and 22 μg/m^3 (P_{75}) for PM_{10}; and 12 ppb (P_{25}) and 20 ppb (P_{75}) for O_3. The modelled pollutant concentration exposures for the study population over the study period are displayed in Box 2. The pollutants showed a clear seasonal cycle with peak NO_2 and CO occurring in the winter months and peak O_3 and PM_{10} occurring in the summer months. Significant correlations were observed between daily concentrations of O_3 and PM_{10} (correlation coefficient [r] = 0.42; $P < 0.01$), and between CO and NO_2 (r = 0.85; $P < 0.01$). O_3 and PM_{10} were negatively correlated with CO and NO_2. The highest

2 Mean (SD) of modelled daily background concentrations of nitrogen dioxide (NO_2), ozone (O_3), carbon monoxide (CO) and particulates (PM_{10}) by month, in south-west metropolitan Perth, Western Australia, 1 January 2002 to 31 December 2006

Month	NO_2 (ppb)	O_3 (ppb)	CO (ppm)	PM_{10} (≤ 10 μm [μg/m³])
January	4.47 (0.91)	20.42 (1.72)	0.12 (0.04)	20.84 (1.58)
February	4.90 (1.04)	19.39 (2.13)	0.13 (0.05)	21.42 (1.69)
March	5.70 (1.04)	18.27 (2.75)	0.16 (0.04)	20.70 (2.03)
April	6.66 (1.03)	15.72 (2.22)	0.24 (0.08)	18.30 (1.48)
May	7.57 (0.98)	14.50 (3.16)	0.35 (0.14)	16.41 (1.55)
June	7.86 (1.12)	14.07 (3.99)	0.40 (0.19)	14.27 (1.16)
July	7.91 (1.28)	16.07 (4.50)	0.38 (0.22)	13.44 (1.14)
August	7.70 (1.28)	18.08 (4.02)	0.34 (0.20)	13.25 (1.00)
September	6.89 (1.38)	20.92 (3.07)	0.23 (0.16)	14.17 (0.98)
October	5.95 (1.10)	21.98 (2.06)	0.16 (0.10)	15.56 (1.31)
November	5.13 (1.02)	22.69 (1.81)	0.12 (0.06)	18.11 (1.75)
December	4.48 (1.02)	21.58 (1.92)	0.10 (0.06)	19.65 (1.98)
All months	6.28 (1.69)	18.73 (4.11)	0.23 (0.17)	17.05 (3.27)

ppb = parts per billion. ppm = parts per million. ◆

negative correlation was observed between O_3 and CO ($r = -0.81$).

Air pollution and ED presentations for asthma

A total of 18 patients re-presented during their referent period, and were subsequently removed from the analyses. Statistically significant increases in odds of ED presentation were only observed for NO_2 and CO, most notably for a 1-day lag, which empirically suggested a 1-day induction period. Analyses for NO_2 and CO were then restricted to this lag period and stratified by age and sex. Significant odds ratios (ORs) were observed for the lowest age group (0–4 years) (Box 3). These patients exhibited a 21% increase in odds per 1 ppb increase in NO_2 (OR, 1.21 [95% CI, 1.03–1.43]), and almost a fivefold increase in odds of ED presentation per 1 ppm increase in CO (OR, 4.92 [95% CI, 1.33–18.15]). When the study sample was stratified by sex, only boys exhibited significant ORs. Among this group, odds of ED presentation were 16% (OR, 1.16 [95% CI, 1.01–1.32]) and four times (OR, 4.13 [95% CI, 1.37–12.45]) higher per 1 unit increase in NO_2 and CO, respectively.

DISCUSSION

The results indicate that increases in daily background air pollution increase the risk of ED presentation of children for asthma. The most recent comparable Australian study was of presentations between 1997 and 2001 in Sydney, and reported a 0.1%–0.4% increase in risk per 1 ppb increase in 1-hour maximum NO_2, and a 3.2% increase in risk per 1 ppm increase in 8-hour average CO.[16] An interquartile range increase in 1-hour NO_2 and 8-hour CO was associated with 1.4% (95% CI, 0.5%–2.4%) and 1.5% (95% CI, 0.6%–2.3%) respective increases in ED presentations among the 1–4-years age group in the Sydney study.[19] The researchers noted that the associations were most consistent for all assessed air pollutants in the lowest age group. Our findings also suggest greater vulnerability among this group. This is yet to be confirmed by international studies — past international studies have tended not to include the very young as a study subgroup,[20,21] despite their potentially greater vulnerability. Our study assessed more recent presentations (2002–2006) and showed a higher risk of ED presentation compared with the Sydney study. We observed a 70% increase in risk per interquartile range increase in 24-hour NO_2 and a 40% increase in risk per interquartile range change in 24-hour CO among the 0–4-years age group. We used 24-hour average concentrations based on the hypothesis that this was the most aetiologically relevant period, considering the potential for cumulative exposure. This period also matched the frequency at which the ED presentations were obtained. Although this may explain the stronger effect sizes observed for NO_2 and CO, it may also have contributed to the non-detection of an effect for other pollutants.

Despite the importance of our findings, this study has some methodological limitations. The power of the study prevented a comprehensive analysis of co-pollutant effects, such as by matching (eg, to investigate the effect of NO_2, we would have had to ensure case and control periods had the same level of CO).[22] The possible effects of CO and NO_2 concentrations on the risk of ED presentation with asthma could not be separated from each other. In addition, the high negative correlation between these two pollutants and O_3 and PM_{10}, possibly because of contrasting meteorological conditions, meant that the strong effects of CO and NO_2 may have masked those of O_3 and PM_{10}. However, these results may not be significantly confounded by meteorological effects (such as temperature), given that a

3 Odds ratios (95% CI) for ED presentations for asthma of 585 children and young adults of south-west metropolitan Perth, Western Australia, by age and sex, after 1-day lagged exposure to NO_2 and CO

	NO_2		CO	
Patients	Per 1 ppb increase	Per IQR (2.81 ppb increase)	Per 1 ppm increase	Per IQR (0.23 ppm increase)
Age				
0–4 years	1.21 (1.03–1.43)	1.70 (1.08–2.69)	4.92 (1.33–18.15)	1.40 (1.06–1.84)
5–9 years	1.01 (0.83–1.23)	1.02 (0.59–1.75)	1.06 (0.22–5.03)	1.01 (0.73–1.39)
10–19 years	1.05 (0.90–1.23)	1.14 (0.75–1.72)	2.62 (0.72–9.55)	1.24 (0.93–1.66)
Sex				
Male	1.16 (1.01–1.32)	1.49 (1.02–2.19)	4.13 (1.37–12.45)	1.35 (1.07–1.71)
Female	1.04 (0.91–1.19)	1.10 (0.77–1.59)	1.63 (0.53–5.03)	1.11 (0.87–1.41)

ED = emergency department. CO = carbon monoxide. IQR = interquartile range. NO_2 = nitrogen dioxide. ppb = parts per billion. ppm = parts per million. ◆

recent multi-city study on hospitalisations for respiratory illness and criteria air pollution found little change in effect estimates after pollutant concentrations were matched to within 1° C of temperature.[7]

Although we restricted our study to an area with minimal non-traffic sources of air pollution, it was impractical to find an urban area completely unaffected by such sources. Non-traffic sources contribute to the modelled background concentrations used as exposures in this study. However, 80% of ambient CO in Perth is derived from motor vehicle emissions.[23] Motor vehicles are also an important source of ambient nitrogen oxide, resulting in 67% of anthropogenic emissions of this pollutant[24] The extent to which motor vehicle traffic contributes to tropospheric-O_3 follows by association, as it is formed by reactions with nitrogen oxides, depending on the exact atmospheric composition. Therefore, CO, NO_2 and O_3 may be reasonably considered as traffic-related ambient air pollutants. Traffic emissions also contain PM_{10}, although the modelled background concentrations are likely to have significant contributions from other sources.

Although we obtained all public ED presentations for our study period, we could not obtain information on those at private hospitals. Such a sample loss may imply that our results relate more to the low-middle socioeconomic class, but this would have little effect on internal validity. External validity is supported by the existence of only one major private hospital with an ED in the study area.

We know of no changes to the diagnostic process or any documented change to the recording of ED information during the study period. However, there is a risk of misdiagnosis because of asthma's similarity with other respiratory diseases such as bronchiolitis, a risk possibly more pronounced for the youngest age group. The observed association with air pollution may relate to symptoms common to asthma and bronchiolitis. A post hoc sensitivity analysis for 1-day lagged NO_2 and CO exposure showed negligible influence on the effect estimates from that presented in Box 3. The OR for a 1 ppb increase in NO_2 among a 1–4-years age group was the same as that for a 0–4-years age group (1.21 [95% CI, 1.03-1.43]). Similarly, there was little change in the OR for a 1 ppm increase in CO exposure (4.87 (95% CI 1.32-17.99) for a 1–4-years age group.

The results of this study indicated that children aged under 5 years were the most vulnerable to increases in traffic-related air pollution and that the most clinically relevant period is exposure on the day before ED presentation.

ACKNOWLEDGEMENTS

We would like to acknowledge the WA Department of Health for provision of Emergency Department Information System data, the WA Department of Environment and Conservation for provision of air monitoring network data, and the Cooperative Research Centre for Asthma and Airways for financially supporting this study.

COMPETING INTERESTS

None identified.

AUTHOR DETAILS

Gavin Pereira, MAppStats, BCM, GCResCom, Epidemiologist[1,2,3]
Angus Cook, MB ChB, PhD, Director, Ecology and Health[1,2]
Annemarie JBM De Vos, PhD, MPH, RN, Epidemiologist[1,2]
C D'Arcy J Holman, MB BS, MPH, PhD, Chair in Public Health[1,2]
1 School of Population Health, University of Western Australia, Perth, WA.
2 Cooperative Research Centre for Asthma and Airways, Sydney, NSW.
3 Telethon Institute for Child Health Research, Centre for Child Health Research, University of Western Australia, Perth, WA.
Correspondence: gavin.pereira@uwa.edu.au

REFERENCES

1 Atkinson RW, Anderson HR, Sunyer J, et al. Acute effects of particulate air pollution on respiratory admissions: results from APHEA 2 project. Am *J Respir Crit Care Med* 2001; 164: 1860-1866.
2 Delfino RJ, Gong Jr H, Linn WS, et al. Asthma symptoms in Hispanic children and daily ambient exposures to toxic and criteria air pollutants. *Environ Health Perspect* 2003; 111: 647.
3 Gálan I, Tobias A, Banegas JR, Aránguez E. Short-term effects of air pollution on daily asthma emergency room admissions. *Eur Respir J* 2003; 22: 802-808.
4 Mortimer KM, Neas LM, Dockery DW, et al. The effect of air pollution on inner-city children with asthma. *Eur Respir J* 2002; 19: 699-705.
5 Brugge D, Durant JL, Rioux C. Near-highway pollutants in motor vehicle exhaust: a review of epidemiologic evidence of cardiac and pulmonary health risks. *Environ Health* [internet] 2007; 6: 23. doi: 10.1186/1476-069x-6-23.
6 Salam MT, Islam T, Gilliland FD. Recent evidence for adverse effects of residential proximity to traffic sources on asthma. *Curr Opin Pulm Med* 2008; 14: 3-8.
7 Barnett AG, Williams GM, Schwartz J, et al. Air pollution and child respiratory health: a case-crossover study in Australia and New Zealand. *Am J Respir Crit Care Med* 2005; 171: 1272-1278.
8 Kolbe J, Vamos M, Fergusson W. Socio-economic disadvantage, quality of medical care and admission for acute severe asthma. *Intern Med J* 1997; 27: 294-300.
9 Lee SL, Wong WHS, Lau YL. Association between air pollution and asthma admission among children in Hong Kong. *Clin Exp Allergy* 2006; 36: 1138-1146.
10 Morgan G, Corbett S, Wlodarczyk J. Air pollution and hospital admissions in Sydney, Australia, 1990 to 1994. *Am Public Health Assoc* 1998; 88: 1761-1766.
11 Neidell MJ. Air pollution, health, and socio-economic status: the effect of outdoor air quality on childhood asthma. *J Health Econ* 2004; 23: 1209-1236.
12 Petroeschevsky A, Simpson RW, Thalib L, Rutherford S. Associations between outdoor air pollution and hospital admissions in Brisbane, Australia. *Arch Environ Health* 2001; 56: 37-52.
13 Kelly AM, Kerr D, Powell C. Is severity assessment after one hour of treatment better for predicting the need for admission in acute asthma? *Respir Med* 2004; 98: 777-781.
14 Government of Western Australia Department of Environment and Conservation. 2006 Western Australian Air Monitoring Report. Perth: DEC, 2007.
15 Pereira G, Cook A. Time series modelling of background air pollution for health studies. In: Clean Air Society of Australia and New Zealand, editor. 19th International Clean Air and Environment Conference; 2009 Sept 6–9; Perth, Australia. http://www.casanz.org.au/
16 Jalaludin B, Khalaj B, Sheppeard V, Morgan G. Effects of ambient air pollution on asthma visits by children to emergency department, Sydney, Australia [abstract]. *Epidemiol* 2005; 16 (5 Suppl): S57-S58.
17 Maclure M. The case-crossover design: a method for studying transient effects on the risk of acute events. *Am J Epidemiol* 1991; 133: 144-153.
18 Hurley PJ, Manins PC, Johnson G, Azzi M. Modelling the winds on days of high ozone in Perth. *Math Comput Model* 1995; 21 (9): 105-110.
19 Jalaludin B, Khalaj B, Sheppeard V, Morgan G. Air pollution and ED visits for asthma in Australian children: a case-crossover analysis. *Int Arch Occup Environ Health* 2008; 81: 967-974.
20 Norris G, Young Pong SN, Koenig JQ, et al. An association between fine particles and asthma emergency department visits for children in Seattle. *Environ Health Perspect* 1999; 107: 489-493.
21 Fauroux B, Sampil M, Quenel P, Lemoullec Y. Ozone: a trigger for hospital pediatric asthma emergency room visits. *Pediatr Pulmonol* 2000; 30: 41-6.
22 Schwartz J. Is the association of airborne particles with daily deaths confounded by gaseous air pollutants? An approach to control by matching. *Environ Health Perspect* 2004; 112: 557.
23 Government of Western Australia Environmental Protection Authority. State of the environment report 2007: Western Australia Atmosphere. Government of Western Australia, 2007.
24 Salisbury J, Ferrari L. National Environmental Health Monographs. Air Series No. 1. Ozone. Department of Human Services, Commonwealth of Australia. 1997. http://www.dhs.vic.gov.au/nphp/enhealth/council/pubs/pdf/ozone.pdf (accessed Sep 2010).

(Received 10 Aug 2009, accepted 22 Jul 2010) ❑