Particulate air pollution and hospital admissions in Christchurch, New Zealand

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Abstract

***Aims**:* Winter air pollution in Christchurch is dominated by particulate matter from solid fuel domestic heating. The aim of the study was to explore the relationship between particulate air pollution and admissions to hospital with cardio-respiratory illnesses.
***Methods**:* Particulate air pollution statistics (PM_{10}) were obtained from the Canterbury Regional Council monitoring station in the city. The New Zealand Health Information Service provided data on admissions to the Princess Margaret and Christchurch Hospitals for the period June 1988 through December 1998 for both adults and children with cardiac and respiratory disorders. The relationship between PM_{10} and admissions was explored using a time series analysis approach controlling for weather variables. Missing values were interpolated from carbon monoxide data for the same time period, as carbon monoxide and PM_{10} were highly correlated.
***Results**:* There was a significant association between PM_{10} levels and cardio-respiratory admissions. For all age groups combined there was a 3.37% increase in respiratory admissions for each interquartile rise in PM_{10} (interquartile value 14.8 mcg/m^3). There was also a 1.26% rise in cardiac admissions for each interquartile rise in PM_{10}. There was no relationship between PM_{10} and admissions for appendicitis, the control condition selected.
***Conclusions**:* In keeping with overseas studies, there is evidence in Christchurch of a relationship between ambient particulate levels and admissions with cardiac and respiratory illnesses. The size of the effect is consistent with overseas data, with the greatest impact for respiratory disorders.
Implications: These results indicate that measures to control ambient particulate levels have the potential to reduce hospital admissions for cardio-respiratory illnesses.

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It has been convincingly demonstrated in a number of European and North American cities that high levels of air pollution are associated with short-term adverse effects on human health.[1-3] The adverse effects have largely been associated with exposure to elevated levels of the particulate component of air pollution[4] and specifically the small sub-10 micron-sized particles (PM_{10}).[5]

The documented adverse health effects from PM_{10} exposure include associated rises in mortality rates, hospital admissions, emergency department visits, as well as increases in symptoms and medication use.[6] Adverse effects have also been demonstrated on lung function.[6] The effects of exposure to high concentrations of inhaled pollutants have largely impacted on respiratory and cardiovascular systems[7] and have recently been related to exposure to even relatively moderate levels of PM_{10} consistently below 100 mcg/m^3.[2] Cumulative evidence from a number of mortality and morbidity studies now suggests that these effects are linear and that there is no threshold concentration below which ambient particulate can be deemed to be free of health effects.[5,8]

To date, there has been relatively little New Zealand-based research examining the relationship between ambient air pollution and either the morbidity or mortality associated with respiratory or cardiovascular illnesses.[9] This lack of research is surprising as parts of New Zealand have clearly been documented to have a significant air pollution problem, most notably the Christchurch urban area, with ambient levels of particulate matter that sometimes surpass those of major North American or European cities[10] and regularly exceed the local guideline of 50 mcg/m^3 as a maximum for the mean daily particulate level.[11] In addition, the prevalence of respiratory disorders, especially asthma, and cardiovascular illnesses are high in this country.[12,13]

Early studies that have been conducted in New Zealand had significant methodological weaknesses, such as a reliance on extrapolated data from overseas work[14] or low power resulting from a small sample size.[15] Recent studies have employed more robust

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methods and have found significant increases in respiratory symptoms and medication usage associated with relatively modest rises in ambient pollution among a susceptible group of subjects with chronic obstructive pulmonary disease[16] and an increase in mortality in relation to a rise in particulate level using a time series study design that controlled for weather variables.[17]

Christchurch is an ideal site for an investigation of the relationship between outdoor air quality and respiratory/cardiovascular admissions: it has one (previously two) main hospital serving the entire city catchment with a computerised patient information system and there is a well-established system for gathering pollution data.

Uniquely in Christchurch, more than 90% of particulate air pollution has been estimated to come from the city's 47,000 wood burners and open fires that are used during the cold winters months.[18] Overseas studies have found that the smoke generated by these sources is associated with the most deleterious effects upon the respiratory and cardiovascular health of local inhabitants.[19] Furthermore, the local weather patterns during the winter months compound the pollution problem. The development of an inversion layer traps warmer air along with large amounts of ambient pollutants at low altitude above the city.[18] Local studies suggest that relatively even mixing of the ambient particulate matter occurs across the Christchurch air-shed over a 24-hour period, implying that there is likely to be a generally homogeneous exposure to similar PM_{10} levels for all city residents.[14] Finally, reliable information on important potential confounders, largely meteorological variables,[1,20] are readily available.

The aim of this study was to assess the relationship between the number of people admitted to Christchurch hospitals each day with respiratory or cardiovascular illness and particulate pollution during the period 1988-98.

Method

Study area

Christchurch has a population of 333,000 people and covers some 452 km^2 on the Canterbury Plains, which are bordered by the Pacific Ocean to the east and the Southern Alps to the west.

Hospital admission data

Hospital admission information was obtained from the New Zealand Health Information Service concerning daily counts of acute hospitalisations for all age groups with the following primary diagnoses based on the International Classification of Diseases, 9th Revision, (ICD 9) classifications: pneumonia (ICD 480-487), acute respiratory infections (460-466), chronic lung diseases (491-492, 494-496), asthma (493), ischaemic heart disease (410-414), dysrhythmia (427) and heart failure (428). Information on appendicitis (540-542) admissions was also included as a control group. Until 1994 the Princess Margaret Hospital (five kilometres south of the other hospital located in the city centre) handled approximately half the medical admissions and so we aggregated admission data for Christchurch Hospital (1988-98) and Princess Margaret Hospital (1988-94) into a single dataset.

Air pollution and meteorology data

Pollution levels were obtained from the Canterbury Regional Council monitoring site in a central Christchurch site for the period June 1988-December 1998. The site is owned by the Ministry of Health and operated and maintained by the Institute of Environmental and Scientific Research Ltd. The information was provided by the Canterbury Regional Council in the form of 24-hour mean concentrations of the following pollutants: carbon monoxide (CO), particulate (PM_{10}), sulphur dioxide (SO_2), and oxides of nitrogen (NO_x).

Over this time around 20% of days were missing particulate pollution data, mostly during the summer of 1993-94 due to equipment malfunction, with the remainder occuring at random. High correlations existed between PM_{10} and the other pollutants, especially CO (the correlation coefficient between PM_{10} and CO was 0.84). A regression was performed on days when values for both PM_{10} and CO existed and the relationship between the pollutants then enabled the determination of missing PM_{10} data. A similar approach was used with the other pollutants (NO_x and SO_2) to fill in remaining gaps. The summer PM_{10} levels were in general low, around one-quarter of the winter PM_{10} levels, and the readings were also virtually constant. As a result any errors in the imputation of the summer data would be small and have limited importance in the subsequent regression calculations.

Only the relationship between particulate pollution and hospital admissions was examined. Meteorological data including wind speed, relative humidity, and temperatures at one metre and 10 metres above ground level were also obtained from the same site.

PM_{10} was monitored using the Rupprecht and Patashnick Co. Inc. Tapered Elemental Oscillating Microbalance (TEOM) device, SO_2 measurements were made by fluorescence (API 100A series, San Diego, US), CO was measured by the gas filter correlation method (API 300, San Diego, US). NO_x monitoring was by an API 200A (San Diego, US) and meteorological measurements were collected by an EASI 950315 (temperature) (Dayton, US), EASI 940919-02 (humidity) (Dayton, US) and Vector A101M (wind speed) (Clwyd, UK). All measurements were subject to regular quality audit using standards adopted by the Ministry of the Environment.

Consent for the study was obtained from the two hospitals, the Canterbury Regional Council and the Canterbury Ethics Committee.

Statistical methods

The analysis was undertaken in two stages using S-PLUS software (http://www.insightful.com/). First, the influence of the meteorological variables on hospital admissions was determined and then the association between the residuals and PM_{10} was modelled. This approach, as successfully used in similar previous studies,[1,21] is considered conservative, and expected to give a minimum value for the pollution's contribution to hospital admissions.

A generalised additive model with a log link[1] was used for the first stage because, although count values are usually Poisson, the mean number of admissions varied with the seasons resulting in an overall non-Poisson distribution.[1] The generalised additive model is an analytical methodology well suited to this type of research[1,21] and one that has been extensively used by researchers.[1,22]

This model was used to find the most likely relationship between weather conditions and admissions, given all the data from 1988 to 1998. The number of admissions predicted by the model was then subtracted from the actual admission values to leave the residual admissions, which were unrelated to the meteorological variables and had a normal distribution. The residuals did not exhibit any significant periodicity and the standard errors were not biased by dispersion. We found that the model took into account two-thirds of the variation in admissions data, although if we had included pollutants in this first stage that value would be lower. This is why our final results show smaller increases than is actually the case. The seasonality in the admissions data is a result of seasonal variations in the other variables and is accounted for by the model.[1]

A linear regression model was used for the second stage to compare these newly calculated admission residuals to the PM_{10} concentrations.[1] Because PM_{10} is significantly higher during the night, admissions were compared on one day with the pollution from the previous night, calculated from 9am on the previous day to 9am on the same day. From this regression the expected increase in admissions due to a given increase in PM_{10} could be calculated.

For each condition, as well as total respiratory and cardiac conditions, an expected percentage increase or decrease in admissions for an interquartile increase of PM_{10} was calculated according to patients in three age groups.

Different lags also needed to be allowed for, as the effects of particulate exposure may be delayed. From a biological perspective, previous research suggested that lag periods would not be important for cardiac illnesses, but that a respiratory admission is more likely a couple of days after a high pollution episode.[6,38] We confirmed this by investigating the results for different lags (from zero to six days), and therefore all cardiac admission results have no lag, and all respiratory results include a two-day lag.

The study was calculated to have sufficient sample size with 18,290 admissions to detect a 1% increase in cardiac admissions for people aged over 64 years, or respiratory admissions for children less than 15 years (20,938 admissions), in relation to a 10 mcg/m^3 rise in particulate level with 80% power. These calculations did not include provision for a threshold, which is consistent with previous research.[6,23]

Results

Summary statistics are given in Table 1 for the daily measurements of pollutants, meteorological variables, and cardio-respiratory admissions for all age groups in Christchurch between 1988-98. During the study period, the interquartile range for PM_{10} recordings was 14.8 mcg/m^3, while the median daily total number of respiratory and cardiac admissions were 10 and 7 respectively.

Table 1: Summary statistics for daily measurements of hospital admissions, air pollutants, and meteorological variables, in Christchurch City (NZ), 1988-98.

Diagnostic category	Mean	SD	Min	Max	IQ range
Cardiac admissions					
Ischaemic heart disease (ICD Nos: 410-14)	4.46	2.37	0	18	3
Heart failure (428)	1.41	1.26	0	9	2
Dysrhythmia (427)	0.96	1.03	0	9	1
Total cardiac admissions (410-14, 427-8)	6.84	3.04	0	22	4
Respiratory admissions					
Acute respiratory infections (460-6)	2.55	2.22	0	17	3
Other diseases of upper tract (470-8)	0.29	0.60	0	6	0
Pneumonia and influenza (480-7)	2.33	2.15	0	17	2
Chronic airways disease (490-2, 494-6)	1.94	1.71	0	11	2
Asthma (493)	3.06	2.02	0	13	2
Total respiratory admissions (460-6, 470-8, 480-7, 490-6)	10.17	5.53	0	38	7
Appendicitis (540-2)	0.93	0.97	0	6	1
Pollutant concentrations					
SO_2 (mg/m^3)	7.84	9.56	0	87	8
NO (mg/m^3)	30.08	59.80	0	709	23
NO_2 (mg/m^3)	19.40	14.69	0	184	17
NO_X (ppb)	32.50	49.57	0	566	26
CO (mg/m^3)	1.16	1.51	0	15.7	1
PM_{10} (mg/m^3)	25.17	25.49	0	283	14.8
Meteorological variables					
Windspeed (m/s)	2.75	1.08	0	6.9	1.47
Temperature at 1m (°C)	12.54	4.85	0.6	28.36	7.3
Temperature at 10m (°C)	11.71	4.44	0.9	26.76	6.52
Relative humidity (%)	75.77	14.63	21.06	100.0	18.33

Table 2: Estimated percentage increase (with 95% confidence intervals) in cardiac or respiratory admissions for different age groups in relation to an interquartile rise in PM_{10} pollution in Christchurch between 1988-98.

	Age 0-14 years	15-64 years	65 and over years	Total for all age groups
Total cardiac admissions[a]	0.21 (-14.49–4.91)	1.33 (-0.24–2.90)	1.22 (0.11–2.33)	1.26 (0.31–2.21)
Total respiratory admissions[b]	3.62 (2.34–4.90)	3.39 (1.85–4.93)	2.86 (1.23–4.49)	3.37 (2.34–4.40)

Notes:
(a) & (b) No lag for cardiac admission, two-day lag for respiratory admissions.

Over the study period the mean annual number of hospital admissions for respiratory conditions rose (see Figure 1). Weather, pollution, and hospital admission (for most conditions) data all exhibited an annual cyclical pattern with peak values generally being recorded during the winter months (see Figure 1).

A significant association was found between particulate pollution and admissions across all age groups for both cardiac and respiratory conditions. An interquartile rise in PM_{10} was associated with a 3.37% (95% CI 2.34–4.40) increase in respiratory admissions and a 1.26% (95% CI 0.31–2.21) increase in cardiac hospitalisations (see Table 2).

The increase in respiratory admissions was similar across all age groups, with children exhibiting a slightly higher increase in hospitalisations.

Total respiratory admissions due to infectious causes; pneumonia/influenza (5.32%, 95% CI 3.46–7.18) and acute respiratory infections (4.53%, 95% CI 2.82–6.24) exhibited the largest increase of all the diagnostic categories in relation to an interquartile rise in PM_{10} (see Table 3). By contrast, there was no significant increase in admissions across all age groups for appendicitis, the control condition, (0.38%, 95% CI -1.87–2.63), or also ischaemic heart disease (0.70%, 95% CI -0.44–1.84) and dysrhythmia (1.08%, 95% CI -1.24–3.40) (see Table 3). However, the study had limited power to explore these subgroups.

For cardiac conditions the associations were strongest when there was no lag in the pollution data (see Table 4). However, for respiratory admissions the increase in admissions was highest when a two-day lag was included in the analysis.

Discussion

The main finding of this study, that an interquartile increase of 14.8 mcg/m^3 in PM_{10} is associated with a significant rise in hospital admissions for both total respiratory (by approximately 3%) and total cardiac (by approximately 1%) conditions, is consistent with previous research conducted in North American and European cities.[1,24-29] Despite the general consistency in the research, there are difficulties with comparing the results of different stud-

Figure 1: Average daily level of PM10 and number of respiratory admissions in Christchurch, 1988-98.

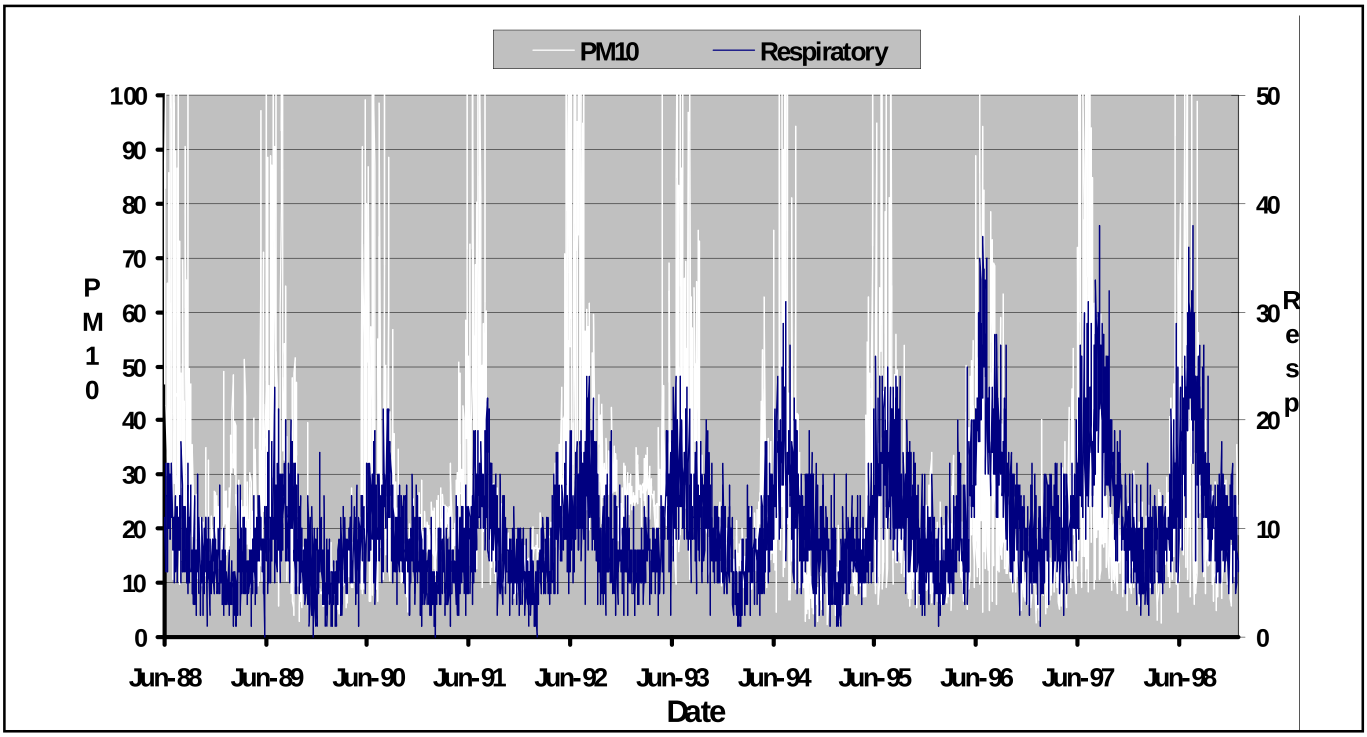

Table 3: Estimated increase in admissions over all age groups for each diagnostic subgroup in relation to an interquartile rise in PM_{10} between 1988-98 in Christchurch.

Admission group	Diagnostic category (ICD Classification Nos)	Percentage increase in total admissions for each diagnostic category (95% CI)
Cardiac (no lag)	Ischaemic heart disease (410-4)	0.70 (-0.44–1.84)
	Heart failure (428)	3.05 (1.16–4.94)
	Dysrhythmia (427)	1.08 (-1.24–3.40)
Respiratory (two-day lag)	Acute respiratory infections (460-6)	4.53 (2.82–6.24)
	Pneumonia/influenza (480-7)	5.32 (3.46–7.18)
	Chronic lung diseases (490-2, 494-6)	3.95 (2.15–5.75)
	Asthma (493)	1.86 (0.48–3.24)
Appendicitis (no lag)	Appendicitis (540-20)	0.38 (-1.87–2.63)

ies because various measures of particulate pollution (black smoke, total suspended particles and PM_{10}) have been used along with different methods to present results (such as a change in admissions per 10 mcg/m^3, 50 mcg/m^3, or interquartile change in level of particulate). The relationships between the various measures of particulate pollution vary with different pollution sources, and comparisons between them can only be general.

There was a significant increase in respiratory admissions in relation to an interquartile rise in particulate matter for all age groups, but the rise was highest among children. Most previous research examining paediatric morbidity and particulate pollution has focused upon outcomes other than hospital admissions and they have often used other study designs.[30-32] Previous time series studies have consistently documented a rise in paediatric hospitalisations in relation to increasing particulate pollution[33] and some researchers have concluded that children are particularly sensitive to the adverse effects of particulate matter.[34]

A significant issue for analyses involving childhood respiratory admissions is the possibility that there may be confounding by epidemics of viral respiratory infections that have been strongly associated with increases in the number of hospital admissions for children.[35,36] The results from this study support the possibility that respiratory infections may act as a confounder as the highest increase in hospitalisations was associated with the diagnostic categories related to respiratory infections (pneumonia and acute respiratory infections). However, the interaction may be more complicated: particulate exposure may be a significant risk factor for more frequent viral respiratory infections, it may exacerbate infectious illnesses, or a viral illness may increase individual susceptibility to the adverse effects of pollution.[37] Future research examining the relationship between particulate exposure and paediatric respiratory admissions must determine how data on respiratory epidemics can be reliably integrated into the analyses.

The results of most time series studies suggest that those at risk of increased, earlier or more severe hospital usage on higher pollution days are those with pre-existing serious cardio-respiratory ill-health.[6,39] It appears likely that in people whose health is already compromised by chronic illness (and ageing), the severity of an acute illness (such as a respiratory infection or congestive heart failure) may be increased on days with high pollution.[6,40] An exception to this mechanism may be asthma, where fine particles may directly provoke an attack of respiratory illness.[5] There is, therefore, likely to be a range of lag periods between exposure to the exacerbating effect of pollution and the need for inpatient treatment related to variability in the severity of the underlying acute illness as well as variations in access to health care. Differences in the lagged responses between the two groups of admissions may reflect distinct mechanisms that determine the pulmonary and cardiac responses after exposure to PM_{10}. Future research should examine in more detail the mechanisms of cardiorespiratory deterioration and pathophysiological changes that occur after this exposure.

The results from the subgroup analyses examining the associations between daily PM_{10} levels and admissions for various diagnostic categories, especially when they were considered in relation to different age groups, were less consistent with previous findings. The increase in admissions for chronic lung disease and asthma among all age groups were similar to the results of Anderson[41] and Sunyer[42] for chronic obstructive airways disease (COAD) and Walters[25] for asthma. The increase in eld-

Table 4: Estimated percentage change in total cardiac or respiratory admissions in relation to different lags of PM_{10} between 1988-98 in Christchurch.

Admissions	Lag of PM_{10} in days						
	0	**1**	**2**	**3**	**4**	**5**	**6**
Total cardiac	1.26 (0.3-2.21)	-0.11 (-1.06–0.84)	0.71 (-0.24–1.66)	0.38 (-0.57–1.33)	0.47 (-0.48–1.42)	-0.02 (-0.9–0.93)	-0.52 (-1.47–0.43)
Total respiratory	2.52 (1.49-3.55)	2.56 (1.53–3.59)	3.37 (2.34–4.40)	3.09 (2.06–4.12)	3.13 (2.10–4.16)	3.21 (2.18–4.24)	3.09 (2.06–4.12)

erly admissions for pneumonia and COAD was also consistent with studies by Schwartz[43] and Moolgavkar.[44] However, in contrast with Pope,[33] no statistically significant association was found in Christchurch between paediatric asthma admissions and PM_{10}. In addition, while Schwartz[28] reported a 1-1.5% increase in admissions for ischaemic heart disease among the elderly, the association in Christchurch did not achieve statistical significance. The absence of a statistically significant relationship between either elderly admissions for ischaemic heart disease or paediatric hospitalisations for asthma and PM_{10} may be due to an inadequate sample size in this study. Although this study had sufficient statistical power to find an association between total cardiac or respiratory admissions and PM_{10}, the number of admissions may have been too small to find any significant associations between individual conditions for different age groups and PM_{10}. Biological plausibility and the findings from previous research suggests that associations may actually exist between admissions for some of these conditions (e.g. dysrhythmia) and particulate pollution.[6]

A major issue in evaluating the association between particulate pollution and morbidity is the relative impact of measurement error in the assessment of exposure and outcome variables. The relatively homogenous exposure of Christchurch residents to pollution and the relatively minor contribution to pollution from non-particulate matter reduces the potential for the study to misclassify exposure.[20] The use of 24-hour averages increases the likelihood that a true catchment-wide measurement of exposure was obtained but a major issue remains about whether outdoor measurements can function as a proxy for personal exposure given that people spend considerable amount of time indoors where they may be exposed to particulate matter from cigarette or cooking smoke. Although small diameter particulate matter can penetrate dwellings and high correlations between environmental recordings and personal exposures to PM_{10} have been recorded[29,45,46] this has yet to be systematically examined, especially in the New Zealand setting.

This study addressed the relationship between particulate levels and hospital admissions and did not consider the role of other pollutants. A notable omission was any data on ozone exposure, despite overseas research that has found a clear association between ozone levels and admission rates for respiratory illnesses.[33,43] However, it should be noted that the association has principally been found in conjunction with summertime, photochemical smog rather than particulate pollution.[42,43] Studies that have concurrently examined the effect of particulate and ozone levels have typically reported that the effect of each is separate.[6] Christchurch is considered unlikely to experience significant effects from ozone, especially during the winter when particulate levels are highest.[18] Although SO_2 and NO_2 have been shown to be related to respiratory admissions, the relationship is neither as consistent, nor as strong, as that with particulate levels, suggesting that these oxides may be exerting an effect mainly through confounding with airborne particulate.[6,33] By contrast, CO and PM_{10} may each exert an independent and additive effect upon cardiac admissions.[28] There is a need for further research to determine the nature and extent of the relationships between particulate matter and gaseous pollutants and to elucidate the toxicological effects of their different combinations.

In conclusion, this study adds to the accumulating evidence that particulate air pollution causes significant morbidity and it augments other local research which has found that exposure to particulate pollution is associated with significant mortality[16] and morbidity[17] in Christchurch. A reduction in ambient particulate pollution levels can therefore be expected to generate significant public health benefits.

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