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ABSTRACT

Background: Both air and noise pollution associated with motor vehicle traffic have been associated with cardiovascular disease. Similarities in pollution source and health outcome mean that there is potential for noise to confound studies of air pollution and cardiovascular disease, and vice versa, or for more complex interactions to occur.

Methods: The correlations between 2-week average roadside concentrations of nitrogen dioxide (NO_2) and nitrogen oxides (NO_X) and short term average noise levels ($L_{eq,5min}$) for 103 urban sites with varying traffic, environment and infrastructure characteristics were examined.

Results: The Pearson correlation coefficient for $L_{eq,5min}$ and NO_2 was 0.53, and for $L_{eq,5min}$ and NO_X , 0.64. Factors influencing the degree of correlation were number of lanes on the closest road, number of cars or trucks during noise sampling and presence of a major intersection.

Conclusions: We recommend measurement of both pollutants in future studies of traffic-related pollution and cardiovascular disease to allow for more sophisticated analysis of this relationship.

Recent studies have reported possible associations between cardiovascular disease and both road traffic noise[1] and road traffic air pollution.[2] Understanding of the adverse effects of each pollutant on the physiology of the cardiovascular system is incomplete; it is hypothesised that air pollution increases blood pressure, contributes to the instability of vascular plaques and may initiate cardiac arrhythmias,[3] while the cardiovascular effects of noise are hypothesised to be stress mediated via stimulation of the hypothalamo-pituary-adrenal and sympathetic-adrenal-medullary axes. Chronic or repeated stimulation of these axes leads to hypertension, accumulation of intra-abdominal fat and insulin resistance.[4] Because both exposures are strongly associated with road traffic, and because of the similarity in health endpoints, there is a possibility that the two pollutants act jointly, or that traffic noise may be a confounding factor in traffic-related air pollution studies and vice versa.

To date, there have been limited attempts to examine the combined effects of noise and air pollution and these have used a variety of approaches and outcomes. A recently published study of road traffic noise and hypertension investigated the joint effect by adjusting for PM_{10} levels in a noise–hypertension model. As this adjustment did not alter the effect estimate of noise on hypertension, the authors concluded that the noise effect was independent but noted study limitations including very small contrast between high and low PM_{10} levels.[5] An investigation of the association between traffic noise and all-cause cardiovascular and respiratory emergency hospital admissions adjusting for air pollution (O_3 and NO_x) found significant increases varying from 3.7% to 5.1% per decibel[6]; however, this study had limited noise exposure data from only six measurement stations across the city of Madrid. Ising *et al* reported that traffic noise was associated with aggravation of bronchitis in children, and that this effect was more important than that of exhaust fumes.[7] The two exposures were highly correlated in their study, which unfortunately had little power. A synergistic effect of traffic-related noise and air pollution on levels of annoyance was shown for a population in the city of Oslo.[8] Other studies have raised the possibility of confounding, but only data on traffic-related noise or on traffic-related air pollution, but not both, were available.[9 10]

Characterising the relationships between exposure to traffic-related noise and traffic-related air pollution would aid the interpretation of previous studies and contribute to the design of new studies. Here we report the correlation between noise and air pollution in a typical urban setting in Vancouver, British Columbia.

METHODS

We collected data on short term average noise levels (equivalent continuous sound level over 5 min, $L_{eq,5min}$) for 103 roadside sites in the Metro Vancouver region of British Columbia. At the same locations, data on 2-week concentration averages for nitrogen dioxide (NO_2) and nitrogen oxides (NO_X) were collected, as described elsewhere.[11] The noise samples were collected at the start of the air pollution sampling period during daytime hours (08:00–18:00). Sampling sites were selected using a location-allocation model that included land use, road networks, population density and regulatory air-quality monitoring to optimally place sampling locations with respect to air pollutants.[12] NO_2 and NO_X 14-day averages were collected with passive samplers equipped with a pre-coated pollutant collection pad (Ogawa USA, Pompano Beach, Florida), and analysis was by liquid chromatography. NO_2/NO_X samplers were positioned approximately 3 m from the ground. Noise levels were measured with an LDL 870 Environmental Noise Analyser (Larson Davis, Provo, Utah) and an LDL 2559 microphone, positioned 1.2 m from the ground at a 90° angle to the roadway. Calibration was

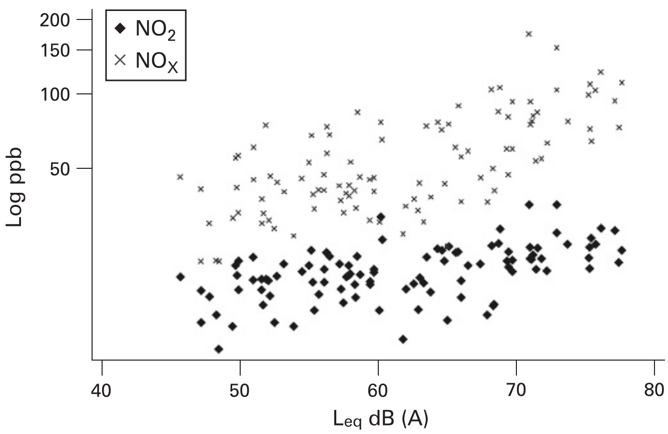

Figure 1 NO_2 and NO_X concentrations by noise level ($L_{eq,5min}$) at 103 measurement sites around Metro Vancouver, BC.

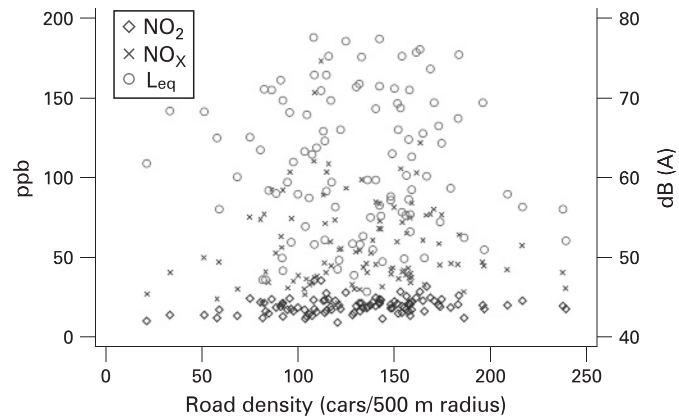

Figure 2 NO_2 and NO_X concentrations and noise level ($L_{eq,\ 5min}$) by traffic density (cars/500 m buffer).

performed with a B&K 4231 calibrator (Bruel & Kjaer, Naerum, Denmark).

For each site information characterising the roadway and surrounding environment was collected, including the following variables that were tested in modelling: time of noise measurement (ie, rush hour), an ordinal subjective measure of car and truck traffic density on the closest roadway, car and truck density on all roads within a 500 m radius, number of lanes on the nearest road, hectares of open land within a 300 m radius, population density within a 750 m radius, and a binary indication of the presence of a four-way or five-way intersection. Input files for the road type, land use and population density measures were taken from the 2001 census prepared by DMTI Spatial (Markham, Ontario). The input file for variables in the vehicle density category was generated by the Metro Vancouver transit authority's EMME/2 model of morning rush-hour traffic volume. Meteorological data (wind speed, direction, rainfall) were collected from the air-quality monitoring network for Metro Vancouver. Distance from sampling site to roads, traffic density, land use and population density were calculated using a geographical information system (ArcGIS, ESRI, Redlands, CA).

Pearson correlation coefficients were calculated to describe the association between traffic-related noise and air pollution. To examine factors influencing the degree of correlation between noise and air pollution, forward stepwise multiple linear regression was performed with NO_2 and NO_X as dependent variables, and $L_{eq,5min}$ as an independent variable; then to examine their effect on reducing unexplained variability, covariates that represented various traffic intensity, infrastructure and environmental factors were added to the regression model. Covariates were retained if they contributed significantly to the regression model ($p<0.05$).

RESULTS

Noise, NO_2 and NO_X all showed fairly monotonic increasing levels of exposure with increasing car and truck traffic, as anticipated (table 1). The rates of increase vary by pollutant and source, however, suggesting that the vehicle fleet mix may result in heterogeneity between noise and air pollutants. The Pearson correlation coefficient for $L_{eq,\ 5\ min}$ and NO_2 was 0.53, and for $L_{eq,\ 5\ min}$ and NO_X, 0.64. Scatter plots in figs 1–3 show the relationship between pollutants, and between the pollutants and two major determinants traffic density and distance to a major road. The correlation between NO_2 and NO_X was 0.87. Simple linear models of NO_2 and NO_X levels with $L_{eq,\ 5\ min}$ as the only independent variable explained 28% and 41% of their variability, respectively, while final models for each explained 56% and 65%, respectively (table 2). Examination of normalised β coefficients suggested that the number of lanes of the nearest road, the presence of a major intersection and traffic density (either car or truck) were the major contributors to variability between noise and the two air pollutants. Other factors that were offered but not retained in either model included population density within a 750 m radius, distance to the nearest road, wind speed and rush hour measurement of noise (08:00–10:00, 16:00–18:00 h).

DISCUSSION

The levels of noise, NO_2 and NO_X reported in this study were similar to levels reported in earlier literature. The correlation observed for noise and NO_2 (0.53) was lower than the finding of 0.84 by Ising *et al*, who also compared actual measurements.[7] It was similar to the results of Klaebo *et al* (0.46) who used modelled values for both noise and air pollution levels[8]; this is of interest as many epidemiological studies rely on modelled exposure estimates for both pollutants. However, the noise and NO_2 correlation was higher than that of Tobias *et al* (0.32) and a related study (0.14), but these had used the fairly crude 24 h averages of noise from six Madrid monitoring stations and NO_2

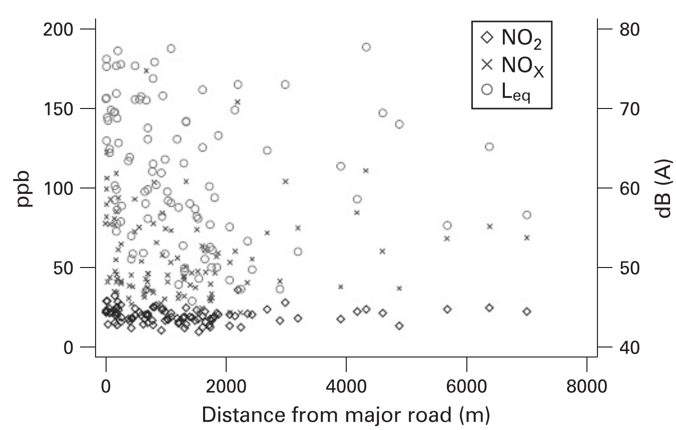

Figure 3 NO_2, NO_X concentrations and noise level ($L_{eq,\ 5min}$) by distance from a major road.

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Table 1 Noise and air pollutant levels by car traffic density (row) and truck density (column)

	n	L_{eq} (dB(A)), mean (SD)	NO_2 (ppb), mean (SD)	NO_X (ppb), mean (SD)
Overall	103	61.7 (8.6)	19.6 (4.9)	57.6 (27.9)
Car traffic				
Very light	29	53.5 (5.0)	17.5 (3.9)	45.2 (17.5)
Light	35	59.2 (5.8)	18.6 (4.3)	45.5 (14.3)
Moderate	17	67.0 (4.3)	19.1 (4.0)	59.4 (23.0)
Heavy	19	72.3 (3.1)	24.4 (5.2)	91.9 (32.8)
Very heavy	3	73.1 (3.7)	23.2 (4.5)	92.1 (17.8)
Heavy truck traffic				
None	54	55.3 (5.1)	17.6 (3.6)	43.8 (14.8)
Very light	19	64.7 (6.0)	19.8 (5.0)	54.3 (21.5)
Light	12	69.8 (2.7)	21.7 (5.9)	74.8 (32.6)
Moderate	10	72.1 (3.3)	23.5 (2.5)	90.3 (18.4)
Heavy	5	73.9 (3.9)	26.2 (6.0)	104.6 (39.7)
Very heavy	3	70.8 (3.9)	20.7 (7.2)	72.8 (32.5)

$L_{eq,5min}$, equivalent continuous sound level over 5 min; NO_2, nitrogen dioxide; NO_X, nitrogen oxides.

Table 2 Multiple linear regression models

Variable	NO_2 model (ppb), β coefficient (SD)	NO_X model (ppb), β coefficient (SD)
R^2	0.56	0.65
Intercept	−0.37 (3.8)	−36.0 (0.039)
Noise (L_{eq}, dBA)	0.24 (0.06)	1.3 (0.31)
Light vehicles per hour per hectare within 500 m	0.01 (0.003)	–*
Heavy truck per hour per hectare within 500 m	–	3.0 (0.83)
Intersection	3.5 (0.87)	16.8 (4.4)
Number of lanes on the closest road		
1	Ref	Ref
2	−3.0 (1.0)	−10.6 (4.8)
4	1.5 (1.3)	17.4 (6.6)
6	−0.33 (1.9)	4.3 (9.6)
Distance to freeway (m)	0.006 (0.0003)	0.004 (0.001)
Kilometres of road network within 300 m radius	0.023 (0.009)	–
Hectares of open land within 300 m radius	–	−0.66 (0.34)

*Not retained in final model.
Coefficients (β's) show increase in air pollutant level (in ppb) per unit increase in the covariate (ie, per 1 dBA increase in noise). $L_{eq,5min}$, equivalent continuous sound level over 5 min; NO_2, nitrogen dioxide; NO_X, nitrogen oxides.

averages from 24 stations.[6 13] Comparison of our observed correlation between measured NO_X and noise (0.64) with previous studies showed a similar pattern to NO_2 (0.21, 0.35, 0.48 in Linares, Tobias and Klaebo, respectively).[6 8 13]

We noted several factors including road layout (eg, the presence of a major intersection), density of traffic (number of cars or trucks within a 500 m radius from EMME/2 models) and urban design (hectares of open land a within 750 m radius) that appeared to influence the variability between noise and the two air pollutants. This variability was not unexpected; while the primary sources of both air and noise pollution are motor vehicles, the generation mechanisms differ, as does the mode of their propagation. While gaseous pollutants result directly from the internal combustion engine, noise is emitted from the engine and tyres and by air displacement. Engine noise predominates below speeds of about 30 km/h for cars (50 km/h for trucks), but at greater speeds "rolling noise" produced by the tyre/road interface predominates.[14] Gaseous air pollutants diffuse and drift and have a wider impact, with a greater contribution of background levels to local effects than does noise. Noise is transmitted by pressure waves that can be reflected and refracted and are increased through superimposition, but otherwise have a short "half-life".

Not all the variability observed was related to these factors, however, and the study had a number of limitations. Principally, the 5 min measurement duration for noise was quite different from the measurement duration for the air pollutants (14 days). However, we examined how representative of longer exposure periods these 5 min samples were by analysing an associated dataset containing 24 h of consecutive 1 min average L_{eq}'s at 30 roadside sites in Vancouver (24 h L_{eq} range 47.5–73.4 dB(A), but without corresponding air pollution data). The 5 min samples taken during daytime over-estimated the 24 h L_{eq} by 1.7 dB(A) (SD 0.3 dB(A)). However, in a simulation study where we repeatedly (n = 10) extracted random daytime 5 min averages from the 30 sites and compared them to their 24 h averages, the mean correlation was 0.97 (SD 2.0). This suggested that the 5 min averages, although slightly biased, are reasonable surrogates of longer term measures, particularly for correlation studies. Many studies rely on such short term measures, and other work has also shown good repeatability of 5 min noise measurements between different seasons.[15] Rain on roads is known to substantially increase noise levels, but we did not obtain sufficient measurements to investigate this factor. In the future, repeated measurements at fewer sites with varying traffic intensity and over a variety of differing environmental conditions would provide more information on the true correlation between traffic noise and traffic-related air pollution. The authors are currently mapping traffic-related noise in the Metro Vancouver region; we will combine this with existing air pollution maps to then examine the joint effects of noise and air pollution exposure on cardiovascular disease in this area.

In summary, it is important to include accurate measurement of both exposures in future studies of traffic pollution and cardiovascular disease. While it may be difficult to separate the effects of traffic noise and traffic-related air pollution, the variability observed here and in other studies suggests it may be possible to disentangle the effects of the two pollutants, especially when those factors known to influence the correlation of the two types of pollutant are considered, and that more sophisticated analysis of potential confounding or effect modification could be undertaken.

Main message

Road traffic noise and air pollution exposures are moderately correlated (Pearson r = 0.5–0.6).

Policy implications

It is recommended that both road traffic noise and air pollution exposures be considered in all future studies of road traffic and cardiovascular disease outcomes.

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