Traffic pollution and the incidence of cardio-respiratory outcomes in an adult cohort in London

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Abstract

Objectives

The epidemiological evidence for adverse health effects of long-term exposure to air and noise pollution from traffic is not coherent. Further, the relative roles of background versus near traffic pollution concentrations in this process are unclear. We investigated relationships between modelled concentrations of air and noise pollution from traffic and incident cardio-respiratory disease in London.

Methods

Among 211,016 adults aged 40-79 years registered in 75 Greater London practices between 2005-2011, the first diagnosis for a range of cardiovascular and respiratory outcomes were identified from primary care and hospital records. Annual baseline concentrations for nitrogen oxide (NO_x), particulate matter with a median aerodynamic diameter <2.5µm ($PM_{2.5}$) attributable to exhaust and non exhaust sources, traffic intensity and noise were estimated at $20m^2$ resolution from dispersion models, linked to clinical data via residential postcode. Hazard ratios were adjusted for confounders including smoking and area deprivation.

Results

The largest observed associations were between traffic related air pollution and heart failure (HR=1.10 for 20 $\mu g/m^3$ change in NO_X, 95%CI 1.01-1.21). However no other outcomes were consistently associated with any of the pollution indicators, including noise. The greater variations in modelled air pollution from traffic between practices, versus within, hampered meaningful fine spatial scale analyses.

Conclusions

The associations observed with heart failure may suggest exacerbatory effects rather than underlying chronic disease. However the overall failure to observe wider associations with traffic pollution may reflect that exposure estimates based on residence inadequately represent the relevant pattern of personal exposure, and future studies must address this issue.

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What this paper adds

- Epidemiological evidence for adverse health effects of long-term exposure to air and noise pollution from traffic is inconsistent.
- We investigated relationships between modelled concentrations of air and noise pollution from traffic and incident cardio-respiratory disease in London.
- The largest observed associations were between traffic related air pollution and heart failure.
- No other outcomes were consistently associated with any of the pollution indicators, including noise.
- Future studies must address whether exposure estimates based on residence adequately represent the relevant pattern of personal exposure.

Introduction

There is now an established body of epidemiological evidence linking long term concentrations of air pollution to adverse health effects,[1] in particular the risk of cardiovascular disease.[2] Air pollution is believed to not only exacerbate existing heart conditions, but may also have a wider role in the development of the disease.[3] While emissions from road traffic sources have been identified as a concern to public health,[4] separating traffic emissions from the regional background pollution levels remains a continuing challenge,[5] and ultimately it is still unclear whether primary traffic air pollution is, on a unit mass basis, more hazardous than background pollution.

Large scale cohort studies have attempted to link different measures of road traffic exposure (related air pollutants, intensity or distance from road) to future disease development or mortality,[6-8] but the overall body of evidence is not coherent. The European cohorts that comprised the ESCAPE (European Study of Cohorts for Air Pollution Effects) project did not find consistent associations between measures of traffic intensity and cardiovascular disease[9]. Nor did the ESCAPE studies find consistent relationships when a range of elemental constituents of particles was considered instead as the exposure.[10] On the other hand, there is growing evidence linking road traffic noise to an increased incidence of hypertension, myocardial infarction and stroke.[11]

Previously we have used a national electronic database of primary care records to study the relationship between long term exposure to air pollution and health.[12 13] The large scale nature of these databases allow us to specifically address whether air pollution could have its effects by increasing the incidence of recorded disease. However, the scale of the pollution model ($1km^2$) previously limited our ability to investigate associations with the incidence of cardiovascular and respiratory disease arising from roadside traffic pollution. In this present study, we use modelled estimates for traffic pollutants and noise, and measures of traffic intensity at a finer spatial scale (residential postcode), to investigate relationships with disease incidence across Greater London.

Methods

Clinical Data Sources

The Clinical Practice Research Datalink (CPRD) is a large, validated primary care database that has been collecting anonymous patient data from participating UK general practices since 1987.[14]. It includes a full longitudinal medical record for all registered patients, which totalled over 12 million by the end of 2014. The database also contains a socioeconomic marker, the Index of Multiple Deprivation (IMD), a composite small-area (approximately 1500 people) measure used in England for allocation of

resources[15]. Approximately three-quarters of the contributing CPRD practices have consented to their data being linked to Hospital Episodes Statistics (HES) data, which records all clinical and administrative information on National Health Service (NHS) funded inpatient episodes. Patient records are linked by a "trusted third party" using their NHS number, sex, date of birth, and postcode.

For this study, we selected practices within the study area bounded geographically by the orbital M25 motorway around Greater London. This identified 75 practices that were continually recording data between 2004 and 2011 within CPRD, and had given consent for their data to be linked to HES.

Road Traffic Based Exposures

Three metrics of road traffic exposure were linked to the CPRD: (i) annual pollution concentrations, (ii) traffic intensity or distance measures, (iii) traffic noise levels.

Modelled annual concentrations for air pollutants were estimated using the KCLurban dispersion modelling system[16] at a resolution of $20m^2$. It incorporates hourly meteorological measurements, empirically derived concentrations of nitrogen oxides (NO_x), ozone (O_3) and particulate matter (PM), and information on source emissions from the London Atmospheric Emissions Inventory. Model validation was carried out by comparing observed versus modelled average monthly concentrations for each of the 96 months between 2003 and 2010. In this paper we present two summaries of indicators of traffic pollution: NO_X and $PM_{2.5}$ (mass of PM with a median aerodynamic diameter <2.5μm) attributable to road traffic sources estimated from the sum of contributions from the following emissions sources: tyre, brake, exhaust, surface wear and resuspension. We also present results for the exhaust and non-exhaust road traffic $PM_{2.5}$ components separately and for NO_2 in supplementary analyses. Within London, the contribution of regional (background) $PM_{2.5}$ to overall levels tends to dominate[16], and in our data this contribution was greater than 85% for 95% of our patients. Therefore, due to this lack of variation across London, we do not present any results for modelled total $PM_{2.5}$.

Traffic proximity measures were developed relating to 'heavy' vehicle density, which was defined as: light goods vehicles, heavy goods vehicles (rigid and articulated trucks/lorries), buses and coaches. We included a distance measure (in metres) from the postcode centroid to the nearest road classified in the top quartile of heavy vehicle intensity. Traffic volume was estimated as total vehicle km driven (heavy vehicles only) in each year for all major roads that fall within a 100m radius of the postcode address centroid. We used a cut-off >100,000km driven to define 'high volume' in the analyses.

Road traffic noise levels were estimated using the TRAffic Noise EXposure (TRANEX) model[17]. This uses information on road traffic flows and speeds, road geography, land cover, and building heights to estimate average sound level pressure (L_{Aeq}) in decibels (dB) over different time periods. Evaluations of TRANEX in other English cities have shown high correlation between modelled and measured one-hour L_{Aeq} (Norwich: r=0.85, Leicester: r=0.95). In our analysis we focused on average annual L_{night} recorded overnight between 23:00-07:00, as this period (i) represents when most of our study subjects would be at their residence, (ii) is when any effects of sleep deprivation are most likely. We provide alternative analyses using daytime noise (L_{Aeq16}) in supplementary analyses, but since it was extremely highly correlated with night noise (r=1.00), it produced identical results. A sensitivity analysis was carried out that excluded patients in postcodes with significant non-traffic transport noise, defined as being within a 50dB noise contour of Heathrow or City airport, or overland rail.

Finally for air pollution, the model estimates were interpolated to postcode level. In the UK these were historically developed for national mail delivery, and are not necessarily geographically consistent units. They may contain up to 100 households, but will typically average about 15 households. We were able to map the address centroid for the 190,115 total London postcodes to the nearest centroid within the each 20m2 grid This was achieved by mapping every London postcode address geometric centroid (n=190,115) to the nearest centroid within each $20m^2$ grid. For the noise model the geometric centroids of the address locations in each postcode were directly used. These were then linked by a "trusted third party" to CPRD, ensuring we had no direct access to the postcodes, preserving patient anonymity.

Cohort and Disease Outcomes Definition

223,264 adults were identified aged 40-79 years registered on 1/1/2005 for >1 year continuously with their practice. From this group, 211,016 (95%) were successfully linked to our traffic based exposures. Non-linkage was mainly due to a few practices being near the study area boundary, so many of their patients' individual postcodes were not eligible. A priori, we chose to assign each patient a fixed level of exposure based on the annual concentrations in the year before baseline (2004), mirroring our previous approach[12].

The first occurrence on the GP or hospital record from 1/1/2005 to 31/12/2011 of the following was searched for: Coronary Heart Disease (CHD), Myocardial Infarction (MI), stroke, heart failure, hypertension, atrial fibrillation, Chronic Obstructive Pulmonary Disease (COPD) & pneumonia. Definitions used Read codes (GP record) based on the Quality and Outcomes Framework[18], which were mapped to corresponding ICD-10 codes, used on the hospital records. Detailed code listings are

available from the authors. Patients with disease outcomes recorded at baseline were excluded from that particular analysis, while patients who de-registered from their practice were censored at that point in time.

Covariates for smoking and BMI were determined from the electronic record, using where possible the last recorded information prior to 2005. Some exceptions included: (i) non-smokers who were reclassified as ex-smokers if they had older historical codes indicating smoking, (ii) never or current smokers whose only status was between 2005-2011, (iii) patients with BMI values after 2005 that were closer in time to the baseline period.

Statistical Analyses

For each pollutant measure we calculated intra-class correlation coefficients (ICC) to estimate the proportion of total variance between the practice clusters. We used Cox proportional hazards models to investigate associations between all traffic exposure measures in the year before baseline (2004) and subsequent incidence. We adjusted cumulatively for (1) age, sex, smoking and BMI and (2) IMD Tenth. Alternate Cox models that stratified on these covariates made no appreciable difference (data not shown). We also investigated the impact of further adjusting pollutant measures for night time noise and vice versa. To account for clustering by practice, the modified sandwich estimate of variance was used to produce robust standard errors. We also investigated models which derive the contribution of between- and within- practice exposure to the overall effect.[12] For air pollution concentrations, we summarised the hazard as approximate inter-quartile range changes (20μg/m^3 for NOx, 1μg/m^3 for $PM_{2.5}$ and 0.3μg/m^3 for $PM_{2.5}$ estimated from exhaust). For night-time noise we used a 5dB change. All analyses were carried out in Stata version 13 (StataCorp LP, College Station, TX, USA).

Results

A summary of the 211,016 patients eligible for the analyses is shown in Table 1. The cohort was 51% male with a mean age of 55.4 years. Table 2 describes the incidence of health outcomes during follow up. For example, n=10,559 (5.00%) had a record of CHD and are not included in the denominator from which n=5,925 (2.96%) were then identified as subsequently being diagnosed with CHD during 2005-2011. Deprivation was related to all incidence rates, except for atrial fibrillation, but was notably stronger for COPD and heart failure.

Table 3 summarises the markers of traffic pollution and noise used in the main analyses (with additional detail provided in Supplemental Material Table S1). NO_x showed extremely high correlation

(r=0.96) with $PM_{2.5}$ attributable from traffic sources, but less so with night noise levels (r=0.40). The ICC's by practice were high for NO_x (ICC=0.80) and $PM_{2.5}$ from traffic sources (ICC=0.67) demonstrating the majority of variation was between practice areas, whereas for night noise (ICC=0.05) most variation was within practice area. This contrast is visually demonstrated in Supplemental Material, Figure S1. Residents in areas with higher NO_x or $PM_{2.5}$ tended to be younger by about 2.5 years on average. Approximately a fifth of the cohort was estimated to live within 100m of a major road. Deprivation was related to all traffic measures, but strongest trends were seen with air pollution rather than distance or noise measures.

The results from the statistical models are shown in Table 4 for CHD, MI stroke and heart failure. There was little evidence that traffic pollution, intensity or noise was related to a higher incidence of CHD, MI or Stroke either before or after adjustment for deprivation. Only intensity and CHD showed a weak positive association after adjustment for deprivation. However for heart failure, there was a positive association with NO_X and $PM_{2.5}$ from traffic sources, which remained statistically significant after adjustment for area deprivation (e.g. HR=1.10, 95%CI 1.01-1.21 for 20µg/m^3 NO_x increase). The relationship with distance measures and noise was also positive, but not statistically significant.

Table 5 summarises results for hypertension, atrial fibrillation, COPD and pneumonia. While all outcomes showed positive associations with air pollution, these were generally explained by adjustment for area deprivation. For intensity and distance measures, the strongest trends were seen with Pneumonia and distance from major road (HR=1.06, 95%CI 0.98-1.14 for 0-100m vs. >250m). There was no evidence of an association between hypertension and night noise (HR=0.99, 95%CI 0.94-1.05 for 60+ dB vs. <55dB), which remained true when analyses were restricted to patients resident in areas not subject to high levels of aircraft or rail noise (Supplemental Material, Table S2).

Associations with all traffic related outcomes were similar when the cohort was restricted to patients registered for >10 years with their practice (Supplemental Material, Table S2). Model effect estimates were broadly similar when they fitted separately to younger and older subjects (Supplemental Material, Table S3), or to never and current smokers (Supplemental Material, Table S4).

Measures of traffic pollution (NO_2 and $PM_{2.5}$ traffic exhaust and non exhaust) produced identical findings due to the high correlation between them (Supplemental Material, Table S5). Partitioning the overall effect into between and within practice estimates for traffic air pollution and noise (Supplemental Material, Table S6) tended to suggest stronger positive effects between practices for all outcomes except for MI, but precision was wide. Further adjusting the air pollution associations for night noise, or vice versa, made no material difference (data not shown).

Discussion

In a longitudinal study using linked electronic primary care and hospital admission records in Greater London, we investigated the associations between cardio-respiratory outcomes and three indicators of exposure to traffic pollution: modelled air pollutants, modelled noise and traffic proximity. Overall, associations between the health outcomes and the various indicators of exposure to traffic pollution were small, inconsistent and lacking in precision but some trends with heart failure and pneumonia were observed.

Strengths and Limitations

We have previously used similar methodology to study disease incidence in the 2000's across England nationally in CPRD,[12] which was similarly inconclusive. While we argued the benefits of linked primary care databases in carrying out large epidemiological analyses, we noted a possible limitation that the earlier pollution model's resolution (1km^2) could not account for potential within urban variations due to busy roads for example. The improved resolution of the dispersion model in this study (20m^2), which can estimate significant changes in exposure of air pollution (NO_x, NO_2) between major roads and suburban background locations,[16] offers a potential benefit to directly study the effects of traffic pollution.

Once modelled air pollution data was linked to patients residential postcodes however, subtle roadside changes predicted by the model were small in comparison to the larger differences estimated between areas, even within Greater London. This is demonstrated by large ICC's (>0.65) for both air pollutants, revealing most modelled variation was between (practice) areas. In other words, patients in the top 10% of NO_x exposure in our study for example were far more likely (77%) to be from an Inner London practice than those not in the top 10% of NO_x (13%). The statistical implication is that the models are predominately estimating a between (practice) area effect for air pollutants, which was confirmed when we partitioned the overall estimate into between and within practice effects. The addition of distance and intensity measures in our study provided a less problematic approach, but did not produce any further evidence of associations with traffic. Another statistical issue was the strong correlation (>r=0.95) between NO_x and our traffic components of $PM_{2.5}$, which effectively eliminated our ability to discern between different contributors of emissions (exhaust vs. non exhaust) or mutually adjust for them. While high correlation between different measures of traffic pollution is to be expected, it may be the dispersion model is being too closely driven by the same predictors, and is under estimating the variation which may be expected from actual measurements.

The lack of variation in our modelled air pollution estimates could be a result of: (i) our sample of practices being under represented by areas where patients live by busy roads, (ii) a high proportion of addresses near busy roads being mapped to postcode centroids which lie further away from the road, or (iii) in outer boroughs of London a much smaller proportion of residents live in close proximity to busy roads. By contrast road traffic noise varied far more within each area, suggesting that there were patients in *all* practices with exposure to high levels of road traffic noise. People from different areas even within the same city, will differ for many reasons besides air quality such as lifestyle or ethnicity, and although adjusting for area deprivation partially addresses this, we cannot discount residual confounding in our results. Finally, like most other large scale cohorts of long term exposure to air pollution, we acknowledge that modelled exposure however accurate will only ever be a proxy for real long term or even lifetime exposure. This is further complicated in London by: (i) a large proportion who commute to work on public transport travelling outside their residential area, (ii) a "revolving door" population where it is estimated every year around 9% of its population moves into London while almost 7% leaves its territory.[19] However, sensitivity analyses restricting to patients who had been registered with their practice for >10 years did not alter our findings.

Finally, a further weakness of our study was the lack of more individual level confounders in the analysis such as ethnicity and educational status, although these will be partly accounted for in the Index of Multiple Deprivation. However we do not believe that the absence of these would account for the overall lack of associations we found across the different exposures and outcomes.

Recent literature of traffic pollution and health in cohort studies

While the effects of long-term exposure to ambient air pollution have been studied in many worldwide settings, few cohort studies have focused on primary traffic pollutants such as NO_x or NO_2, and of those that have, have used mortality as the outcome. The Dutch NLCS study[6] found associations between NO_2 and Black Smoke and mortality, with associations highest for respiratory causes. Recent studies in Rome[8] and California[7] also reported positive associations between NO_2 and mortality, with strongest trends among deaths from cardiovascular causes. While the ESCAPE meta-analyses of 11 European cohorts[20] found associations between PM_{10}, $PM_{2.5}$ and the incidence of coronary events, these relationships were not seen for either NO_x or NO_2. Another ESCAPE meta-analyses of 19 cohorts was unable to find consistent evidence between a comprehensive set of elemental constituents of PM and overall cardiovascular mortality.[10]

Recent cohort studies have measured alternative measures of traffic pollution, such as intensity on the nearest road[6 8] or road traffic noise[21]. The NLCS study found elevated associations between traffic

intensity and mortality from IHD, cerebrovascular causes and heart failure, not explained by adjustment for traffic noise. Evidence from ESCAPE also showed associations between traffic load on major roads within 100m of residence and hypertension across 15 population based cohorts.[22] Meta-analyses of road traffic noise mainly across Europe showed a 3% increased risk in hypertension prevalence per 5dB increase in daytime noise,[23] and a 8% increase in CHD risk per 10dB of weighted day-noise level.[24]

How our study fits in

While we were unable to replicate many of the positive findings from recent cohort studies, there are important differences to consider. In the Rome study,[8] associations with their indicators of traffic were only statistically significant after adjustment for socio-economic status. Adjustment for deprivation in our study had the opposite effect, as more deprived areas were associated with more traffic pollution in our sample of practices in Greater London. This was a pattern we previously observed nationally,[12] and has been recently replicated by a study of air pollution inequality at regional and city levels across England.[25] Studies which additionally explored individual as well as neighbourhood measures of socio-economic status, generally replicated this relationship,[26] with New York a notable exception where affluent areas were located in high density areas close to busy roads[1]. Increased gentrification of inner cities over time may change the relationship between pollution and socio-economic status, and although we found no evidence of this, we were likely underrepresented in very central affluent London areas. However this seems an unlikely explanation for the lack of associations with air pollution that were mostly null before any adjustments for deprivation. Another explanation may be the reduced exposure range in comparison to previous studies such as the ACS[1], where our inter-quartile range for modelled $PM_{2.5}$ in Greater London in 2004 (1µg/m^3) was approximately a quarter of what was estimated in the ACS in 1999-2000. However many of our hazard ratios were very close to or below 1, suggesting further scaling of estimates would still not produce comparable associations.

We also found little evidence of any associations with traffic noise, whether we used daytime or night noise measures which were very highly correlated. This contrasts with recent findings linking noise levels derived from the same model to hospital admissions for stroke across London.[27] In addition, it had little effect when added as an adjustment factor when estimating associations with air pollution. The failure to find any association with hypertension contrasts with a predominately European meta-analysis of 24 observational studies from 1970-2010, all smaller in size to ours.[23] It may be that the traffic noise model used here is too crude to detect small health effects, failing to account for location of bedrooms within a house, or whether windows are open or closed at night.[11] Aircraft noise levels

in London have been shown to be associated with increased risks of stroke and CHD hospital admissions and mortality[28]. However, excluding patients who lived in areas exposed to major levels of noise pollution from aircraft or rail, did not materially alter our findings for traffic noise. Finally, the exposure range in noise levels across greater London may be different to studies that have shown positive associations. For example the inter-quartile range of estimated night noise levels in Vancouver (50-58dB)[29] was twice that seen in our study(49-52dB). The NLCS study[21] used a reference category of ≤50dB daytime noise in analyses; by contrast in our study nobody was estimated to have daytime noise of ≤54dB. The Vancouver study also suggested that the relationship between noise and CHD mortality was non-linear and only seen in the top decile,[29] however risks were similar when we compared patients in the top decile of exposure (≥60dB) to those with lower categories.

Heart Failure & Pneumonia

Our analyses provided evidence linking exposure to air pollution from traffic and the incidence of heart failure and to lesser extent pneumonia, which follows on from similar associations found with air pollution in our national study on incidence[12] and mortality.[30] Neither disease outcome has been well studied among the air pollution literature, though a link between air pollution and heart failure has been recently speculated upon,[3] and a meta-analysis of time-series studies estimated increased risk of hospitalisation or death from heart failure with daily levels of $PM_{2.5}$ and NO_2.[31] The NLCS study[21] reported associations with heart failure mortality and pollution concentrations at home address (NO_2, $PM_{2.5}$), but not with intensity or distance from major road, which were unaffected by adjustment for noise, all which mirrored our findings. Most air pollution studies of pneumonia have focused on short term effects of exposure, but a study in Canada found associations with long term exposure to NO_2 and $PM_{2.5}$ and hospitalisation for community acquired pneumonia.[32]

As heart failure often represents the end stage for cardiovascular disease, associations here may represent an exacerbatory effect of air pollution in a group primarily older with more co-morbidity[33]. For example, among our heart failure incident cases two-thirds already had been diagnosed with COPD at baseline, while about a third (31%) had CHD; two-thirds (68%) of pneumonia cases were aged ≥60 years. There is a strong socio-economic trend with heart failure[34], also seen in our study, which suggests we cannot rule out residual confounding as an explanation as we were unable to adjust for individual deprivation.

Conclusion

Our results suggest that adults living in inner London, or near busy roads, are not at greater risk of developing cardio-respiratory diseases despite being potentially exposed to higher average levels of traffic pollution and noise. They may however be at increased risk of exacerbations of heart failure and pneumonia which are more likely to result from shorter term exposure. We cannot rule out associations with longer term exposure and underlying disease, as our pollution models cannot accurately represent the reality of long term exposure for individuals, especially within a dynamic population such as London. Although our large cohort study offers greater statistical power, future smaller studies with better exposure assessment may be of more value. Only by shifting measurement of exposure from places to people will we be better able to answer the epidemiological question of whether traffic pollution leads to more disease.

Acknowledgments

Contributorship

HRA, RWA, DGC and FJK conceived the study. SB, DD and JG provided the exposure data and assisted with the linkage process. IMC helped oversee the extraction of the clinical records, designed and undertook the analysis. All authors contributed to the development of the project methodology, interpretation of the results, and drafting of the paper.

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Competing Interests

There are no competing interests.

Table 1 – Summary of cohort registered on 1/1/2005

Variable	Grouping	N	%
	All	211,016	**100%**
Gender	Men	107,226	**50.8%**
	Women	103,790	**49.2%**
Age	40-64	161,325	**76.5%**
	65-79	49,691	**23.6%**
Smoking	Never	105,614	**50.1%**
	Ex (amount unknown)	17,418	**8.3%**
	Ex (Light)	18,199	**8.6%**
	Ex (Heavy)	8,840	**4.2%**
	Current (amount unknown)	2,294	**1.1%**
	Current (Light)	28,483	**13.5%**
	Current (Heavy)	14,503	**6.9%**
	Missing	15,665	**7.4%**
BMI	10-20	9,589	**4.5%**
	20-25	64,304	**30.5%**
	25-30	61,384	**29.1%**
	30-40	31,573	**15.0%**
	40+	3,436	**1.6%**
	Missing	40,730	**19.3%**
Index of Multiple Deprivation	1 (Least)	40,830	**19.4%**
	2	49,494	**23.5%**
	3	41,282	**19.6%**
	4	51,123	**24.2%**
	5 (Most)	28,287	**13.4%**
Practice Borough	Inner	40,647	**19.3%**
	Outer	170,639	**80.7%**
Registration Length	<10 years	79,797	**37.8%**
	10+ years	131,219	**62.2%**
High exposure to Aircraft or Rail Noise[a]	No	155,670	**73.8%**
	Aircraft or Rail	55,346	**26.2%**

[a] - Lives in postcode within the 50dB noise contour of Heathrow or City airport, or overland rail

Table 2 – Disease outcomes summary between 2005-2011 (n=211,016)

Outcome	ICD-10 Codes	Has prior diagnosis on GP record by 1/1/2005		No history of disease on 1/1/2005	Gets 1st Read code diagnosis or hospital admission 2005-2011		Most deprived IMD quintile vs. least
		n	%	n	n	%	Adjusted HR[a]
CHD	I20-I25	10,559	**5.00%**	200,457	5,925	**2.96%**	1.19
Myocardial infarction	I21-I23	3,974	**1.88%**	207,042	2,582	**1.25%**	1.26
Stroke	I63, I63-I64	3,969	**1.88%**	207,047	3,716	**1.79%**	1.20
Heart failure	I50	1,801	**0.85%**	209,215	2,224	**1.06%**	1.80
Atrial fibrillation	I46-I49, R00.1	2,967	**1.41%**	208,049	4,846	**2.33%**	0.96
Hypertension	I10, I15	41,167	**19.51%**	169,849	17,785	**10.47%**	1.45
COPD	J41-J44	3,780	**1.79%**	207,236	7,518	**3.63%**	1.86
Pneumonia	J12-J18	2,967	**1.41%**	208,049	4,846	**2.33%**	1.50

[a] Hazard Ratio for IMD adjusted for age, sex, smoking and BMI

Table 3 – Summary of NO_x, $PM_{2.5}$ (road traffic sources only), traffic volume, major road distance and night noise (n=211,016)

Traffic exposure	Level	N	NO_X (mean ±SD)	$PM_{2.5}$ due to Traffic (mean ±SD)	L_{night} (mean ±SD)	Age at baseline (mean ±SD)	Current smokers (%)	Most deprived IMD 5th (%)	Correlations				
									ICC[b]	NO_X	$PM_{2.5}$ Traffic	Km driven	Dis-tance
NO_X ($\mu g/m^3$)	0-55	68,644	48.2 ±4.4	1.0±0.1	50.9 ±2.9	56.4 ±11.2	21.7	6.4	0.80	_	0.96	0.47	-0.41
	55-75	101,287	63.3 ±5.4	1.4±0.2	51.8 ±4.1	55.4 ±11.0	20.6	12.7					
	75+	41,085	86.8 ±11.8	2.3±0.5	55.0 ±6.6	53.9 ±10.8	23.3	23.3					
$PM_{2.5}$ from traffic sources ($\mu g/m^3$)	0-1	32,322	44.8 ±3.5	0.9±0.1	50.1 ±1.8	56.4 ±11.2	22.2	6.1	0.67	0.96	_	0.58	-0.43
	1-2	152,042	62.0 ±9.1	1.4±0.3	51.6 ±3.8	55.5 ±11.1	20.8	11.2					
	2+	26,652	90.5 ±12.8	2.5±0.5	57.5 ±6.9	54.0 ±10.8	24.1	31.5					
Vehicle km Driven[a]	None	119,984	58.8 ±11.6	1.3±0.3	49.9 ±1.2	55.5 ±11.0	20.8	11.1	0.07	0.47	0.58	_	-0.32
	Low Vol.	63,455	64.5 ±14.8	1.5±0.5	54.4 ±5.1	55.5 ±11.2	21.8	13.4					
	High Vol.	27,677	77.2 ±19.6	2.1±0.8	56.2 ±6.8	55.1 ±11.1	23.4	22.9					
Distance(m) to major road	>250m	95,481	57.5 ±12.0	1.2±0.4	50.9 ±3.3	55.6 ±11.1	21.1	10.7	0.28	-0.41	-0.43	-0.32	_
	100-250m	71,328	64.0 ±12.9	1.5±0.4	51.2 ±3.2	55.2 ±11.0	21.0	14.1					
	0-100m	44,207	73.1 ±18.5	1.9±0.7	56.2 ±6.3	55.4 ±11.1	22.8	22.8					
L_{night} (dB)	0-55	172,940	60.8 ±13.2	1.4±0.4	50.1 ±1.2	55.4 ±11.1	21.3	13.1	0.05	0.40	0.52	0.59	-0.27
	55-60	16,467	64.8 ±15.6	1.6±0.5	57.5 ±1.5	55.9 ±11.1	21.1	11.3					
	60+	21,609	78.3 ±19.3	2.2±0.7	63.7 ±2.8	55.2 ±11.1	22.7	17.1					

[a] Within 100m radius, with >100,000km driven annually was defined as High Volume.

[b] Intra class correlation by practice cluster.

Table 4 – Hazard ratios for incident CHD, MI, stroke & heart failure during 2005-2011 by traffic related exposures

Exposure	Unit/category	CHD (n=200,457)		MI (n=207,042)		Stroke (n=207,047)		Heart failure (n=209,215)	
		HR1[a] (95% CI)	**HR2**[b] (95% CI)	**HR1**[a] (95% CI)	**HR2**[b] (95% CI)	**HR1**[a] (95% CI)	**HR2**[b] (95% CI)	**HR1**[a] (95% CI)	**HR2**[b] (95% CI)
NO_X	20µg/m^3 change	**1.00** (0.96,1.04)	**0.97** (0.93,1.01)	**0.94** (0.88,1.01)	**0.91** (0.84,0.98)	**0.94** (0.89,0.99)	**0.90** (0.85,0.96)	**1.18** (1.08,1.28)	**1.10** (1.01,1.21)
% $PM_{2.5}$ due to Traffic	1µg/m^3 change	**0.99** (0.94,1.05)	**0.96** (0.91,1.02)	**0.92** (0.84,1.02)	**0.88** (0.79,0.98)	**0.93** (0.86,1.10)	**0.88** (0.81,0.97)	**1.25** (1.11,1.40)	**1.15** (1.02,1.30)
Vehicle km Driven[c]	None	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
	Low Volume	**0.95** (0.91,1.01)	**0.95** (0.90,1.00)	**0.99** (0.91,1.08)	**0.98** (0.90,1.07)	**1.02** (0.96,1.11)	**1.02** (0.95,1.10)	**0.98** (0.90,1.06)	**0.96** (0.88,1.04)
	High Volume	**1.07** (1.00,1.15)	**1.05** (0.98,1.13)	**0.99** (0.88,1.12)	**0.97** (0.86,1.09)	**1.00** (0.88,1.15)	**0.98** (0.86,1.12)	**1.09** (0.96,1.23)	**1.02** (0.90,1.16)
Distance(m) to major road	>250m	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
	100-250m	**1.00** (0.94,1.07)	**0.99** (0.93,1.06)	**0.96** (0.88,1.06)	**0.95** (0.87,1.05)	**1.01** (0.94,1.09)	**1.00** (0.93,1.08)	**1.09** (1.00,1.20)	**1.06** (0.97,1.17)
	0-100m	**1.03** (0.96,1.11)	**1.02** (0.95,1.09)	**0.97** (0.87,1.09)	**0.96** (0.85,1.07)	**0.99** (0.89,1.11)	**0.98** (0.87,1.09)	**1.06** (0.95,1.19)	**1.02** (0.91,1.14)
L_{night}	<55dB	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
	55-60	**0.88** (0.79,0.99)	**0.88** (0.79,0.98)	**0.90** (0.79,1.03)	**0.91** (0.79,1.03)	**0.97** (0.86,1.09)	**0.97** (0.86,1.10)	**0.87** (0.74,1.02)	**0.88** (0.75,1.03)
	60-	**1.01** (0.93,1.10)	**1.00** (0.93,1.09)	**1.00** (0.86,1.15)	**0.99** (0.86,1.14)	**0.93** (0.83,1.05)	**0.92** (0.82,1.04)	**1.12** (0.96,1.29)	**1.09** (0.94,1.26)

[a] HR1: Age, gender, smoking & BMI. [b] HR2: As HR1, plus additional adjustment for IMD. [c] Within 100m radius, with >100,000km driven annually was defined as High Volume.

Table 5 – Hazard ratios for incident hypertension, atrial fibrillation, COPD & pneumonia during 2005-2011 by traffic related exposures

Exposure	Unit/category	Hypertension (n=169,849)		Atrial fibrillation (n=208,049)		COPD (n=204,256)		Pneumonia (n=207,901)	
		HR1[a] (95% CI)	**HR2**[b] (95% CI)	**HR1**[a] (95% CI)	**HR2**[b] (95% CI)	**HR1**[a] (95% CI)	**HR2**[b] (95% CI)	**HR1**[a] (95% CI)	**HR2**[b] (95% CI)
NO_X	20µg/m^3 change	**1.10** (1.01,1.21)	**1.05** (0.97,1.14)	**1.10** (1.01,1.21)	**1.05** (0.97,1.14)	**1.06** (0.90,1.25)	**0.99** (0.86,1.13)	**1.11** (1.02,1.19)	**1.06** (0.98,1.14)
% $PM_{2.5}$ due to Traffic	1µg/m^3 change	**1.11** (0.97,1.26)	**1.03** (0.91,1.16)	**0.97** (0.90,1.04)	**0.98** (0.91,1.06)	**1.08** (0.86,1.34)	**0.98** (0.81,1.18)	**1.11** (1.00,1.23)	**1.04** (0.95,1.15)
Vehicle km Driven[c]	None	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
	Low Volume	**0.99** (0.93,1.06)	**0.98** (0.93,1.04)	**0.99** (0.93,1.06)	**0.98** (0.93,1.04)	**0.97** (0.89,1.06)	**0.96** (0.89,1.03)	**1.05** (0.97,1.14)	**1.03** (0.95,1.12)
	High Volume	**1.05** (0.97,1.13)	**0.99** (0.93,1.06)	**1.05** (0.97,1.13)	**0.99** (0.93,1.06)	**1.01** (0.91,1.11)	**0.94** (0.86,1.03)	**1.05** (0.96,1.16)	**1.01** (0.91,1.11)
Distance(m) to major road	>250m	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
	100-250m	**0.99** (0.93,1.06)	**0.98** (0.93,1.04)	**1.01** (0.95,1.06)	**1.00** (0.95,1.06)	**0.94** (0.86,1.03)	**0.92** (0.84,1.01)	**1.05** (0.97,1.13)	**1.03** (0.96,1.11)
	0-100m	**1.05** (0.97,1.13)	**0.99** (0.93,1.06)	**1.02** (0.94,1.10)	**1.02** (0.94,1.11)	**0.93** (0.84,1.02)	**0.90** (0.81,0.99)	**1.08** (1.01,1.17)	**1.06** (0.98,1.14)
L_{night}	<55dB	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
	55-60	**1.00** (0.93,1.07)	**1.01** (0.94,1.08)	**0.93** (0.85,1.02)	**0.93** (0.85,1.01)	**0.87** (0.77,0.99)	**0.88** (0.77,1.00)	**0.95** (0.84,1.07)	**0.95** (0.85,1.08)
	60-	**1.01** (0.95,1.07)	**0.99** (0.94,1.05)	**0.95** (0.88,1.03)	**0.95** (0.88,1.04)	**1.00** (0.91,1.10)	**0.98** (0.89,1.08)	**0.98** (0.88,1.08)	**0.96** (0.87,1.07)

[a] HR1: Age, gender, smoking & BMI. [b] HR2: As HR1, plus additional adjustment for IMD. [c] Within 100m radius, with >100,000km driven annually was defined as High Volume.

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Supplemental Material

Title: Traffic pollution and the incidence of cardio-respiratory outcomes in an adult cohort in London

Authors: IM Carey, HR Anderson, RW Atkinson, S Beevers, DG Cook, D Dajnak, J Gulliver, FJ Kelly.

Contents

Figure S1 – Practice means, and 10th and 90th percentiles for NO_x and L_{night}

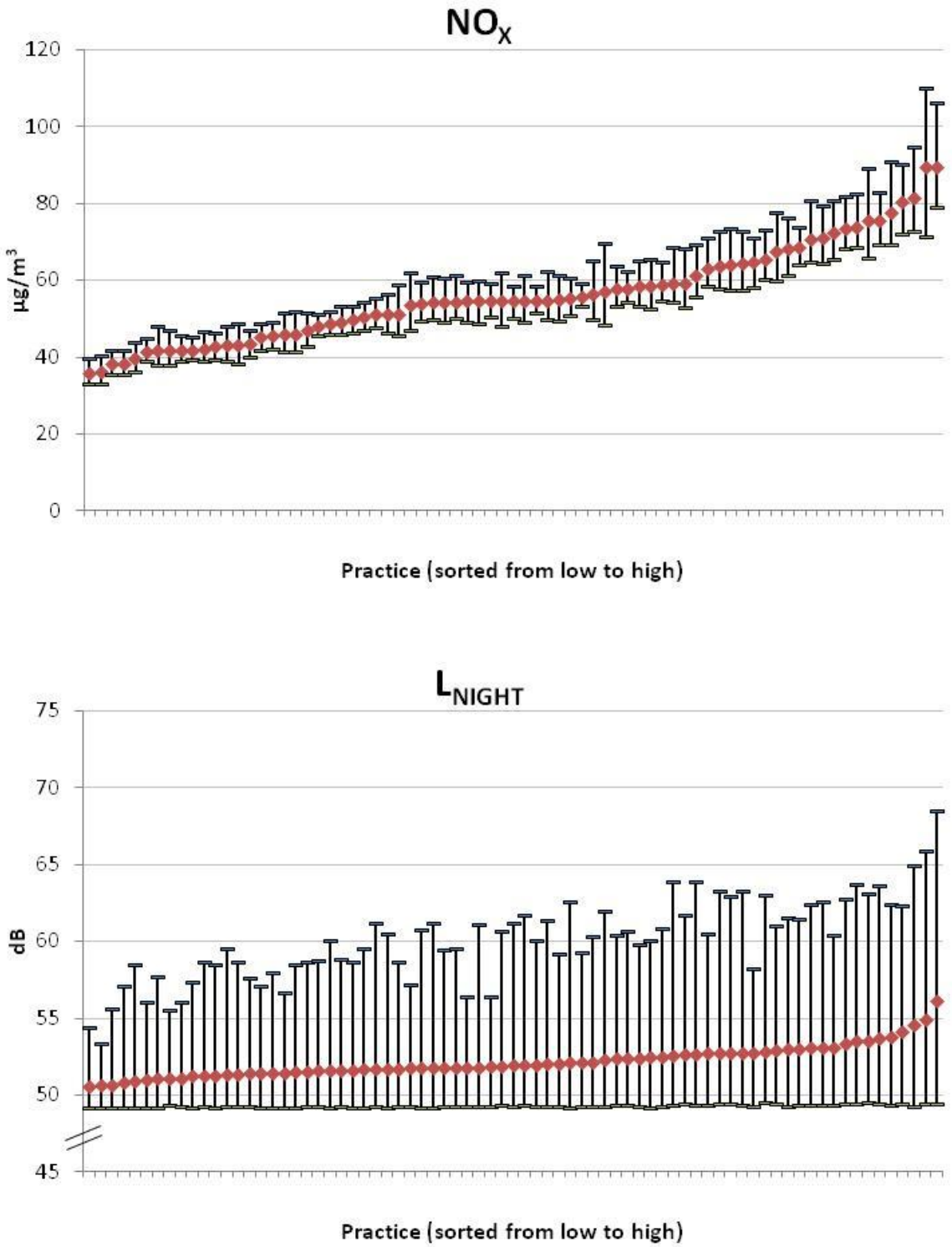

Table S1 – Mean and correlation summary for traffic air pollutants and night noise

Traffic Exposure	Mean	Std Dev	Inter Quartile Range	ICC†	Correlations between pollutants					
					NO_2	NO_X	$PM_{2.5}$ exhaust	$PM_{2.5}$ non-exhaust	$PM_{2.5}$ traffic sources	L_{night}
NO_2	37.4	5.8	7.6	0.86	_	0.99	0.93	0.92	0.94	0.35
NO_X	63.0	15.1	18.6	0.80		_	0.95	0.94	0.96	0.40
$PM_{2.5}$ exhaust	0.80	0.30	0.31	0.70			_	0.95	0.99	0.49
$PM_{2.5}$ non-exhaust	0.65	0.23	0.28	0.61				_	0.99	0.56
Combined $PM_{2.5}$ from traffic sources	1.45	0.52	0.60	0.67					_	0.52
Night Road Traffic Noise (L_{night})	52.1	4.6	2.6	0.05						_

Table S2 – Hazard ratios for incident CHD, heart failure, hypertension during 2005-11 by NO_x, $PM_{2.5}$ (traffic sources only) and L_{night} restricted to patients based on registration length or aircraft/rail noise profiles

Traffic Exposure	Unit/category	CHD				Heart failure				Hypertension			
		Base model		Base + IMD		Base model		Base + IMD		Base model		Base + IMD	
		HR	95% CI	**HR**	95% CI	**HR**	95% CI	**HR**	95% CI	**HR**	95% CI	**HR**	95% CI
Patients registered in same practice for 10+ yrs (n=131,219)													
NO_X	20µg/m^3 change	**0.99**	0.93-1.04	**0.96**	0.91-1.01	**1.18**	1.07-1.30	**1.11**	1.01-1.23	**1.08**	1.00-1.17	**1.04**	0.96-1.13
$PM_{2.5}$ Traffic	1µg/m^3 change	**0.98**	0.91-1.05	**0.94**	0.87-1.02	**1.25**	1.10-1.42	**1.16**	1.02-1.32	**1.08**	0.96-1.21	**1.02**	0.90-1.14
L_{night}	60-dB vs. <55dB	**0.98**	0.87-1.10	**0.97**	0.87-1.09	**1.02**	0.84-1.24	**1.00**	0.82-1.22	**0.99**	0.92-1.06	**0.97**	0.91-1.04
Patients resident in area of non Aircraft or Rail noise pollution (n=155,670)													
NO_X	20µg/m^3 change	**1.00**	0.96-1.04	**0.97**	0.93-1.02	**1.22**	1.11-1.33	**1.15**	1.03-1.28	**1.11**	1.01-1.23	**1.06**	0.97-1.16
$PM_{2.5}$ Traffic	1µg/m^3 change	**1.00**	0.94-1.06	**0.97**	0.91-1.03	**1.30**	1.15-1.46	**1.21**	1.05-1.38	**1.13**	0.98-1.29	**1.05**	0.92-1.20
L_{night}	60-dB vs. <55dB	**0.99**	0.90-1.09	**0.99**	0.90-1.08	**1.12**	0.95-1.32	**1.10**	0.93-1.29	**1.01**	0.95-1.08	**1.00**	0.94-1.06

Base model: Age, gender, smoking & BMI.

Table S3 – Hazard ratios for all outcomes during 2005-2011 for NO_x, $PM_{2.5}$ (traffic sources only) and L_{night} stratified by age

Exposure	Age (yrs)	Unit	CHD		MI		Stroke		Heart failure	
			HR	95% CI	**HR**	95% CI	**HR**	95% CI	**HR**	95% CI
NO_x	Age <65y	20µg/m^3 change	**0.95**	0.90-1.01	**0.87**	0.78-0.96	**0.86**	0.79-0.92	**1.04**	0.89-1.23
	Age ≥65y	20µg/m^3 change	**1.00**	0.93-1.06	**0.94**	0.86-1.04	**0.94**	0.86-1.02	**1.13**	1.03-1.24
$PM_{2.5}$ Traffic	Age <65y	1µg/m^3 change	**0.95**	0.88-1.03	**0.86**	0.75-0.98	**0.82**	0.73-0.92	**1.06**	0.84-1.33
	Age ≥65y	1µg/m^3 change	**0.97**	0.88-1.07	**0.90**	0.78-1.04	**0.94**	0.83-1.06	**1.20**	1.07-1.34
L_{night}	Age <65y	60-dB vs. <55dB	**1.01**	0.90-1.13	**1.03**	0.86-1.24	**0.88**	0.78-1.17	**0.99**	0.75-1.32
	Age ≥65y	60-dB vs. <55dB	**1.00**	0.88-1.13	**0.95**	0.78-1.16	**0.95**	0.82-1.10	**1.12**	0.96-1.31
			Hypertension		**Atrial fibrillation**		**COPD**		**Pneumonia**	
NO_x	Age <65y	20µg/m^3 change	**1.03**	0.95-1.13	**0.94**	0.87-1.01	**1.00**	0.85-1.17	**1.03**	0.94-1.13
	Age ≥65y	20µg/m^3 change	**1.10**	1.01-1.19	**1.01**	0.95-1.07	**0.98**	0.86-1.11	**1.08**	1.00-1.17
$PM_{2.5}$ Traffic	Age <65y	1µg/m^3 change	**1.01**	0.89-1.14	**0.93**	0.83-1.04	**1.01**	0.82-1.25	**1.01**	0.89-1.15
	Age ≥65y	1µg/m^3 change	**1.10**	0.98-1.24	**1.02**	0.93-1.11	**0.95**	0.80-1.13	**1.08**	0.98-1.20
L_{night}	Age <65y	60-dB vs. <55dB	**0.95**	0.89-1.01	**0.92**	0.78-1.09	**1.03**	0.89-1.19	**0.97**	0.81-1.15
	Age ≥65y	60-dB vs. <55dB	**1.09**	1.01-1.19	**0.97**	0.88-1.07	**0.93**	0.81-1.07	**0.96**	0.84-1.11

All Hazard Ratios adjusted for Age, gender, smoking, BMI & IMD.

Table S4 – Hazard ratios for all outcomes during 2005-2011 for NO_x, $PM_{2.5}$ (traffic sources only) and L_{night} stratified by smoking

Exposure	Smoking	Unit	CHD		MI		Stroke		Heart failure	
			HR	95% CI	**HR**	95% CI	**HR**	95% CI	**HR**	95% CI
NO_x	Never	20µg/m^3 change	**1.02**	0.95-1.09	**0.92**	0.82-1.03	**0.87**	0.80-0.94	**1.11**	0.99-1.25
	Current	20µg/m^3 change	**0.94**	0.88-0.99	**0.89**	0.81-0.97	**0.90**	0.80-1.01	**1.17**	1.03-1.34
$PM_{2.5}$ Traffic	Never	1µg/m^3 change	**1.03**	0.93-1.14	**0.90**	0.77-1.06	**0.84**	0.74-0.96	**1.14**	0.98-1.32
	Current	1µg/m^3 change	**0.90**	0.83-0.98	**0.85**	0.74-0.97	**0.87**	0.73-1.04	**1.25**	1.03-1.50
L_{night}	Never	60-dB vs. <55dB	**1.16**	1.03-1.32	**1.06**	0.84-1.33	**0.83**	0.69-1.01	**1.14**	0.92-1.41
	Current	60-dB vs. <55dB	**0.84**	0.72-1.00	**0.87**	0.70-1.07	**0.99**	0.81-1.22	**0.98**	0.69-1.41
			Hypertension		**Atrial fibrillation**		**COPD**		**Pneumonia**	
NO_x	Never	20µg/m^3 change	**1.05**	0.97-1.13	**0.97**	0.91-1.03	**0.98**	0.79-1.21	**1.09**	0.99-1.20
	Current	20µg/m^3 change	**1.07**	0.97-1.18	**0.96**	0.86-1.07	**1.01**	0.87-1.16	**1.07**	0.97-1.18
$PM_{2.5}$ Traffic	Never	1µg/m^3 change	**1.03**	0.92-1.16	**0.95**	0.86-1.05	**0.98**	0.74-1.32	**1.08**	0.95-1.24
	Current	1µg/m^3 change	**1.05**	0.91-1.21	**0.97**	0.83-1.14	**1.01**	0.84-1.22	**1.03**	0.91-1.17
L_{night}	Never	60-dB vs. <55dB	**0.99**	0.92-1.06	**0.94**	0.82-1.08	**0.94**	0.72-1.22	**1.09**	0.91-1.31
	Current	60-dB vs. <55dB	**0.98**	0.90-1.08	**0.92**	0.74-1.14	**1.04**	0.91-1.17	**0.90**	0.73-1.11

All Hazard Ratios adjusted for Age, gender, smoking, BMI & IMD.

Table S5 – Hazard ratios for all outcomes during 2005-2011 for pollutants not in main paper - NO_2, $PM_{2.5}$ (exhaust) and $PM_{2.5}$ (traffic non-exhaust)

Exposure	Unit	CHD		MI		Stroke		Heart failure	
		HR	95% CI	**HR**	95% CI	**HR**	95% CI	**HR**	95% CI
NO_2	10µg/m^3 change	**0.97**	0.91-1.02	**0.88**	0.79-0.97	**0.88**	0.82-0.95	**1.15**	1.02-1.30
$PM_{2.5}$ Traffic Exhaust	0.5µg/m^3 change	**0.96**	0.91-1.01	**0.89**	0.82-0.98	**0.90**	0.83-0.97	**1.14**	1.02-1.27
$PM_{2.5}$ Traffic Non-Exhaust	0.5µg/m^3 change	**0.97**	0.91-1.04	**0.87**	0.77-0.98	**0.87**	0.79-0.97	**1.16**	1.02-1.31
		Hypertension		**Atrial fibrillation**		**COPD**		**Pneumonia**	
NO_2	10µg/m^3 change	**1.07**	0.96-1.20	**0.98**	0.91-1.05	**0.98**	0.82-1.18	**1.08**	0.98-1.20
$PM_{2.5}$ Traffic Exhaust	0.5µg/m^3 change	**1.04**	0.93-1.15	**0.99**	0.92-1.06	**0.99**	0.84-1.18	**1.04**	0.95-1.14
$PM_{2.5}$ Traffic Non-Exhaust	0.5µg/m^3 change	**1.02**	0.90-1.16	**0.98**	0.90-1.06	**0.96**	0.79-1.16	**1.05**	0.95-1.16

All Hazard Ratios adjusted for Age, gender, smoking, BMI & IMD.

Table S6 – Hazard ratios for between and within practice effects for all outcomes during 2005-2011 by NO_x, $PM_{2.5}$ (traffic sources only) and L_{night}

Exposure	Unit	Within or Between practice	CHD		MI		Stroke		Heart failure	
			HR	95% CI	**HR**	95% CI	**HR**	95% CI	**HR**	95% CI
NO_x	20µg/m^3 change	Between	**0.97**	0.88-1.07	**0.85**	0.73-0.99	**1.02**	0.91-1.15	**1.09**	0.93-1.28
		Within	**1.00**	0.92-1.09	**1.03**	0.91-1.18	**0.89**	0.79-1.00	**1.03**	0.90-1.18
$PM_{2.5}$ Traffic	1µg/m^3 change	Between	**0.95**	0.84-1.07	**0.79**	0.66-0.95	**0.97**	0.85-1.11	**1.18**	0.96-1.44
		Within	**0.99**	0.91-1.09	**1.02**	0.89-1.18	**0.90**	0.79-1.03	**1.04**	0.90-1.21
L_{night}	5 dB change	Between	**0.99**	0.82-1.19	**0.84**	0.63-1.13	**1.06**	0.83-1.35	**1.48**	1.07-2.05
		Within	**0.99**	0.96-1.01	**1.00**	0.96-1.05	**0.97**	0.93-1.01	**1.01**	0.96-1.06
			Hypertension		**Atrial fibrillation**		**COPD**		**Pneumonia**	
NO_x	20µg/m^3 change	Between	**1.15**	1.03-1.28	**1.00**	0.89-1.13	**1.06**	0.84-1.33	**1.13**	0.99-1.29
		Within	**0.94**	0.89-0.99	**0.97**	0.88-1.09	**0.94**	0.86-1.03	**0.96**	0.88-1.06
$PM_{2.5}$ Traffic	1µg/m^3 change	Between	**1.18**	0.99-1.41	**0.99**	0.86-1.13	**1.08**	0.78-1.50	**1.17**	0.98-1.39
		Within	**0.93**	0.87-0.98	**0.99**	0.88-1.11	**0.93**	0.84-1.02	**0.95**	0.85-1.05
L_{night}	5 dB change	Between	**1.20**	0.83-1.74	**1.13**	0.92-1.39	**1.15**	0.71-1.87	**1.22**	0.92-1.62
		Within	**0.99**	0.97-1.00	**0.98**	0.96-1.01	**0.98**	0.95-1.01	**0.98**	0.94-1.01

All Hazard Ratios adjusted for Age, gender, smoking, BMI & IMD.