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Title: Does exposure to aircraft noise increase the mortality from cardiovascular disease of the population living in the vicinity of airports? Results of an ecological study in France.

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Abstract

Objective: The impact of aircraft noise on health is of growing concern. We investigated the relationship between this exposure and mortality from cardiovascular disease, coronary heart disease, myocardial infarction and stroke.

Methods: We performed an ecological study based on 161 *communes* (the smallest administrative unit in France) close to three major French airports: Paris-Charles de Gaulle, Lyon Saint-Exupéry and Toulouse-Blagnac. The mortality data were provided by the French Center on Medical Causes of Death for the period 2007-2010. Based on data provided by the French Civil Aviation Authority, a weighted average exposure to aircraft noise (L_{den}AEI) was computed at the *commune* level. A Poisson regression model with *commune*-specific random intercepts, adjusted for potential confounding factors including air pollution, was used to investigate the association between mortality rates and L_{den}AEI.

Results: Positive associations were observed between L_{den}AEI and mortality from cardiovascular disease (adjusted mortality rate ratio (MRR) per 10 dB(A) increase in L_{den}AEI = 1.18; 95% confidence interval: 1.11 to 1.25), coronary heart disease (MRR = 1.24 (1.12 to 1.36)) and myocardial infarction (MRR = 1.28 (1.11 to 1.46)). Stroke mortality was more weakly associated with L_{den}AEI (MRR = 1.08 (0.97 to 1.21)). These significant associations were not attenuated after adjustment for air pollution.

Conclusions: The present ecological study supports the hypothesis of an association between aircraft noise exposure and mortality from cardiovascular disease, coronary heart disease and myocardial infarction. However, the potential for ecological bias and the possibility that this association could be due to residual confounding cannot be excluded.

Key words: Aircraft noise; environment; mortality; health.

Introduction

The impact of exposure to aircraft noise on health is of growing concern[1] because of a steady rise in flights and because people's annoyance with this noise also seems to be rising.[2] While many studies address annoyance associated with aircraft noise[3-5] or report adverse effects on sleep quality,[6-8] much fewer consider other health effects of this noise exposure such as cardiovascular disease. Noise is a psychosocial stressor that activates the sympathetic and endocrine system. According to the general stress model,[9] neuroendocrine arousal is associated with adverse metabolic outcomes that are well-known and established risk factors for cardiovascular disease. Therefore, aircraft noise exposure could increase the prevalence or incidence of these diseases, ultimately increasing the risk of premature death.

Several studies have shown an association between aircraft noise exposure and hypertension.[10-13] A multi-airport study in the United States found that high exposure to aircraft noise was significantly associated with hospitalisation for cardiovascular disease among people older than 65 years living near airports.[14] The evidence for an association of aircraft noise with mortality is currently limited. In 2010, Huss *et al.*[15] reported an association between aircraft noise and mortality from myocardial infarction in Switzerland, with a dose-response relationship for level and duration of noise exposure, but no association with stroke or cardiovascular mortality. A Danish study did not find any association of aircraft noise with stroke mortality[16] neither did a Canadian study with coronary heart disease mortality.[17] More recently, a small area study near Heathrow airport in London showed a significant association between high levels of aircraft noise and hospital admissions and mortality for stroke, coronary heart disease and cardiovascular disease.[18]

We performed an ecological study addressing the issue of an association between weighted average exposure to aircraft noise and mortality for some specific causes of interest:

cardiovascular disease, coronary heart disease, myocardial infarction and stroke. Since air pollution has been found to be associated with cardiovascular disease,[19-21] concerns for disentangling the effects of noise and of air pollution on cardiovascular outcomes have been raised.[1] A secondary aim of the present study was therefore to examine if the association between aircraft noise and mortality was confounded by air pollution.

Methods

Spatial scale

We performed an ecological study based on 161 *communes* (the smallest administrative unit in France) spread over three geographical areas located in the vicinity of three major French airports (Figure 1): Paris-Charles de Gaulle (108 *communes*), Lyon Saint-Exupéry (31 *communes*) and Toulouse-Blagnac (22 *communes*) (hereafter, respectively referred to as the area of Paris, Lyon and Toulouse). In 2011, Paris-Charles de Gaulle airport counted about 61 million passengers, Lyon Saint-Exupéry airport about 8.5 million passengers, and Toulouse-Blagnac airport about 7 million passengers.[22] The study population corresponded to the population of these 161 *communes* living in the vicinity of these three airports and was estimated at 1.9 million inhabitants in 2009 (that is 3% of the total population of mainland France).

Aircraft noise exposure and mortality data used in the present study were obtained at the *commune* level.

Aircraft noise exposure assessment

The estimated exposure to aircraft noise was assessed by the French Civil Aviation Authority which produces outdoor noise exposure maps with the ‘Integrated Noise Model’[23] for France's largest airports. The Integrated Noise Model (INM) is an internationally well-established computer model that evaluates aircraft noise impacts in the vicinity of airports. The INM outputs noise contours for an area. Aircraft noise contours were available for the year 2008 for Paris-Charles de Gaulle airport, 2003 for Lyon-Saint-Exupéry airport and 2004 for Toulouse-Blagnac airport. For Lyon-Saint-Exupéry and Toulouse-Blagnac airports, we used the most recent noise exposure data available. These aircraft noise contours were considered to be representative for the years preceding the mortality assessment. The study area

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comprises all the *communes* exposed to aircraft noise, defined as being included in these noise contours but also the *communes* sharing a common border with them. Including these neighbouring *communes* allowed us to increase contrast in aircraft noise exposure.

The noise indicator used in the present study is the day-evening-night equivalent level (L_{den}) in decibels A (dB(A)). It is defined as a weighted average of sound pressure levels from day (6 am-18 pm), evening (18 pm-22pm) and night (22 pm-6 am). It is determined over the year at the most exposed façade. In this calculation, evening and night sound pressure levels receive a penalty of 5 dB(A) and 10 dB(A), respectively, to reflect people's sensitivity to noise.[24] Noise levels were estimated with a 1-dB (A) resolution from a minimum of 50 dB(A) for the Paris area, and 45 dB(A) for both Lyon and Toulouse areas. For each *commune* of the study area, the number of inhabitants of the *commune* living within these noise levels that are at 1-dB (A) intervals was available based on the 2009 French census.

Noise levels were aggregated to obtain an estimate of *commune*-level exposure to aircraft noise. A population-weighted average called average energetic index (L_{den}AEI)[25] was estimated by weighting, for a given *commune*, the L_{den} by the number of inhabitants living within this noise level. For a given *commune* i, L_{den}AEI was defined as follows:

$$L_{den}AEI_i = 10\log_{10}\left(\frac{1}{\sum_k P_k}\sum_{j\geq 1} P_j 10^{\frac{L_{den,j}}{10}}\right).$$

where $L_{den,j}$ is the noise level j (the difference between $L_{den,j}$ and $L_{den,j+1}$ is 1 dB(A)), P_j the number of inhabitants in the *commune* exposed to $L_{den,j}$ dB(A) and $\sum_k P_k$ is the total number of inhabitants in the *commune.*

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$L_{den}AEI$ was then used as a measure of aircraft noise exposure in the statistical analyses presented in the present paper.

Air pollution exposure assessment

Information on exposure to air pollution including both nitrogen dioxide (NO_2) and particulate matter of 10 microns or less (PM_{10}) was available at the *commune* level but only for the *communes* of Paris and Lyon areas. Dispersion modelling was used to estimate annual background air pollution concentration for each *commune* of the study area. Briefly, modelled concentrations were provided at a 50 m × 50 m resolution by Airparif institute for the Paris area, and at a resolution of 1,000 m × 1,000 m by Air Rhône-Alpes institute for the Lyon area. For both areas, modelled concentrations were validated by comparison with concentrations measured by a monitoring station network. The average air pollution exposure (for both NO_2 and PM_{10} indicators and expressed in $\mu g/m^3$) for the years 2008-2010 was used in the statistical analyses. It was then categorised into three categories corresponding to the tertiles of the distribution.

Mortality data

The mortality data were provided by the French Center on Medical Causes of Death (CépiDc-Inserm) for the period 2007-2010. The tenth revision of the International Classification of Diseases (ICD-10) was used to code and classify mortality data based on death records. The *commune* of residence, which is systematically included in the death record, was used as the spatial location.

Four underlying causes of death were investigated in the present study: 1) cardiovascular disease (I00-I52), 2) coronary heart disease (I20-I25), 3) myocardial infarction (I21-I22) and 4) stroke (I60–I64, excluding I63.6).

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Statistical Analysis

Correlations between aircraft noise and air pollution exposure were assessed using Spearman's rank correlation coefficients.

The effects of aircraft noise on mortality rates were first examined with Poisson Generalized Additive Mixed Models (GAMMs)[26-27] including a smooth cubic spline function in order to account for a potential non-linear effect. As the smoothed fit does not deviate from the linear fit for L_{den}AEI, associations with the continuous exposure variable were then estimated and presented in the present paper. We fitted Poisson Generalized Linear Mixed Models (GLMMs)[28] including a *commune*-specific random effect term to account for over-dispersion. For each outcome, the GLMMs model could be written as follows:

$$Y_i | u_i \sim \mathrm{Poisson}(\mu_i = \mathrm{Pop}_i \theta_i)$$

$$\log(\mu_i) = \log(\mathrm{Pop}_i) + \beta^t X_i + u_i$$

where i refers to the *commune*, Y_i denotes the number of deaths observed in the *commune* i, Pop_i the population number in the *commune* i (considered as an offset), X_i a vector of explanatory covariates for adjustment, and u_i represents the corresponding random effect. β^t denotes the regression coefficients corresponding to these covariates. As usual, the non-spatial random effect, u_i, also called heterogeneity, was assumed to be normally distributed with a zero mean and a constant variance.

Data on potential confounders

The models were adjusted for the following covariates, at the *commune* level, considered to be a priori confounding factors: gender, age, log-population density, lung cancer mortality and a deprivation index. The log-population density was introduced instead of the population

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density in order to take into account the fact that the density was greatly different from one *commune* to the other.

Lung cancer mortality (ICD-10 code: C34) was used at the *commune* level as a proxy measure for *commune*-level smoking because data on individual smoking or smoking prevalence at the *commune* level were not available in France.

As using the Townsend deprivation index[29] in France may be not suitable for different reasons[30-31], we preferred to introduce the deprivation index proposed by Rey *et al.*.[32] It was constructed at the *commune* level based on four variables, each representing a dimension of socioeconomic level: (1) the median household income, (2) the percentage of high school graduates in the population aged 15 years and older, (3) the percentage of blue collar workers in the active population, and (4) the unemployment rate. These socioeconomic data were provided by the French National Institute for Statistics and Economic Studies (INSEE).

Our deprivation index was defined as the first component of a principal component analysis (PCA) of the four variables. This index accounted for 67 % of the total variation of the model and was strongly correlated with each of the initial variables (positively with the unemployment rate and the percentage of blue-collar workers and negatively with income and the percentage of high school graduates). Positive values of the deprivation index correspond to deprived *communes*.

Adjusted mortality rate ratios (MRR) with their 95% confidence intervals (95% CIs) were computed for each covariate included in the models by taking the exponential of the corresponding regression coefficient.

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Additional analyses were also performed to examine the impact of air pollution on the relationship between aircraft noise exposure and mortality by adjusting the models on air pollution (NO_2 and PM_{10} concentrations).

Sensitivity analyses

The models were stratified on gender to test whether the potential associations between aircraft noise exposure and mortality from the causes of interest remained similar, for both men and women.

The Townsend deprivation index was introduced in the models instead of the deprivation index obtained with the PCA.

As aircraft noise levels were assumed to be much higher in the Paris area than in the other areas due to the larger size of the airport, the effect of the additional adjustment for the study area was explored and a sensitivity analysis using the Paris data only was conducted.

The version 10.1 of the ArcGIS software[33] was used to produce the maps. All the data management was conducted using SAS software[34] version 9.3 and statistical analyses were conducted using R statistical software[35] version 3.0.2 with the gam function of the *mgcv* package.[36]

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Results

Overall, the average L_{den}AEI was estimated to 49.6 dB(A) (range: 42.0 - 64.1 dB(A)) as shown in Table 1. Half of the *communes* of the study area had an L_{den}AEI lower than 48.9 dB(A). The highest average of L_{den}AEI was observed in the Paris area (51.6 dB(A) compared to 45.3 dB(A) for the Lyon area and to 45.7 dB(A) for the Toulouse area). The *commune* with the highest L_{den}AEI (64.1 dB(A)) was located in the Paris area. Moreover, L_{den}AEI varied more widely in the Paris area. The NO_2 concentration was higher in the Paris area (mean: 24.0 $\mu g.m^{-3}$) than in the Lyon area (mean: 16.5 $\mu g.m^{-3}$) and varied more widely in the Paris area. The PM_{10} concentrations were very similar in both areas.

Figure 2 shows the distribution of L_{den}AEI in the *communes* included in the study area according to the quartiles of L_{den}AEI. A fairly increasing pattern of L_{den}AEI was observed on both west and east sides of the Paris-Charles de Gaulle airport, whereas no specific geographical pattern of L_{den}AEI was found either for the Lyon area or for the Toulouse area.

Adjusted MRRs derived from the models are presented in Table 2. Increased MRRs were observed with increasing age for mortality from all specific causes of interest. The population density was negatively associated with mortality from all specific causes of interest except stroke. The deprivation index was associated with mortality from all specific causes of interest, showing an increase in mortality for the most deprived *communes*. The lung cancer mortality was not associated with any specific cause of interest.

Increasing L_{den}AEI was associated with mortality from cardiovascular disease (MRR per 10 dB(A) increase in L_{den}AEI = 1.18 (1.11 to 1.25)), coronary heart disease (MRR = 1.24 (1.12 to 1.36)), and myocardial infarction (MRR = 1.28 (1.11 to 1.46)). L_{den}AEI was more weakly associated with stroke mortality (MRR = 1.08 (0.97 to 1.21)).

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Supplementary results with adjustment for air pollution

Aircraft noise levels (L_{den}AEI) were moderately correlated to NO_2 concentrations (ρ = 0.45) while they were not correlated to PM_{10} concentrations (ρ = 0.06). The correlation between L_{den}AEI and NO_2 concentration was lower for the Paris area (ρ = 0.26). NO_2 and PM_{10} concentrations were positively correlated (ρ = 0.64).

When NO_2 concentration was taken into account in the models including L_{den}AEI, the results did not change (Table 3).

Introducing PM_{10} concentration in the model instead of NO_2 concentration did not change the results.

Sensitivity analyses

When stratified by gender, MRRs were higher in men than in women for mortality from cardiovascular disease, coronary heart disease and myocardial infarction. After adjustment for NO_2 concentration, MRRs per 10 dB(A) increase in L_{den}AEI were respectively 1.29 (1.17 to 1.42) and 1.12 (1.03 to 1.23) for mortality from cardiovascular disease, 1.29 (1.12 to 1.49) and 1.15 (0.97 to 1.37) for mortality from coronary heart disease, and 1.37 (1.11 to 1.68) and 1.21 (0.94 to 1.55) for mortality from myocardial infarction (Table 3).

Introducing the Townsend deprivation index in the models did not change the results (Table 3). The Townsend deprivation index was highly correlated with the deprivation index obtained with the PCA (ρ = 0.85).

The additional adjustment for the study area in the models did not alter the results (Table 3). Moreover, the associations between aircraft noise exposure and mortality from all causes of interest remained similar when only the Paris data were used (Table 3).

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Discussion

The present study is the first ecological study investigating the relationship between exposure to aircraft noise and the mortality of the population living in the vicinity of airports in France. This study covers 161 *communes* of France with a population of 1.9 million people living close to Paris-Charles de Gaulle, Lyon-Saint-Exupéry and Toulouse-Blagnac airports. Positive associations were reported between weighted average exposure to aircraft noise and mortality from cardiovascular disease, coronary heart disease and myocardial infarction. Controlling for the socioeconomic status of the *commune* (measured by a deprivation index), demographic factors of the *commune* (such as age and gender of the inhabitants), and lung cancer mortality used as a proxy for smoking did not change the results. When the models were stratified on gender, the associations between exposure to aircraft noise and mortality from cardiovascular disease, coronary heart disease and myocardial infarction remained significant with higher risks among men than women.

As aircraft noise levels were much higher in the Paris area than in the other areas due to the larger size of the airport, the effect of the additional adjustment for the study area was explored and a sensitivity analysis using the Paris data only was conducted, but the results remained similar.

The present study seems to confirm the findings of recent studies suggesting that high levels of aircraft noise are associated with mortality from cardiovascular disease and coronary heart disease,[18] and with mortality from myocardial infarction.[15] Moreover, we observed a week association between aircraft noise and stroke mortality: these results are in accordance with the results of Huss *et al.*[15] and of Sorensen *et al.*.[16]

The present study has attempted to take into account the issue of confounding air pollution. Accounting for NO_2 or PM_{10} concentration did not change the results: air pollution does not

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seem to be a confounding factor in the relationship between aircraft noise and mortality from all causes of interest. These results are consistent with previous studies. Huss and colleagues[15] found that the association between aircraft noise and mortality from myocardial infarction was not attenuated with adjustment for air pollution. Correia *et al.*[14] showed that the association between high exposure to aircraft noise and hospitalisation for cardiovascular disease among people older than 65 years remained after controlling for air pollution. Hansell *et al.*[18] reported that the significant association between high levels of aircraft noise and mortality for stroke, coronary heart disease and cardiovascular disease was robust to adjustment for PM_{10} concentration.

Strengths and limitations of this study

The number of *communes* (n=161) included in the study area was relatively small compared to the number of geographical units included in other studies investigating the relation between aircraft noise and mortality or hospitalisation. Hansell *et al.*[18] studied the risks for hospital admissions in 12,110 census output areas and the risks for mortality in 2,378 super output areas. Correia *et al.*[14] estimated the percentage increase in the zip code level hospital admission rate associated with a 10 dB(A) increase in the zip code level aircraft noise for 2,218 zip codes surrounding 89 airports in the United States.

However, the first major strength of the present study is both the accuracy and the exhaustiveness of the mortality data provided by the French Center on Medical Causes of Death (CépiDc-Inserm) and the large number of deaths from cardiovascular disease (7,450) for a four-year period (2007-2010). The second interest of the present study is that the ecological approach allowed us to take advantage from large contrasts in exposure between geographical units to evidence small associations between mortality and aircraft noise exposure: L_{den}AEI varied from 42.0 to 64.1 dB(A) at the *commune* level.

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Depending on the airports, exposure to aircraft noise for the years 2003, 2004 and 2008 was used and mortality data for the period 2007-2010 were examined, thus not allowing us to take into account a possible latency period between exposure and mortality, especially in the Paris area. For Lyon-Saint-Exupéry and Toulouse-Blagnac airports, we used the most recent noise exposure data available. For the Paris-Charles de Gaulle airport, we compared noise maps for the years 2008 and 2011 and we found that they were very similar. As no other information was available for Lyon and Toulouse areas and as noise contours seem to be stable over the period 2008-2011, the noise contours used in the present study were considered to be representative for the years preceding the mortality assessment.

The use of the population-weighted average of exposure to aircraft noise (L_{den}AEI) in the models allowed us to take into account a part of the variability of aircraft noise exposure within the *communes*. There was no other alternative to consider this variability because both mortality data and exposure to aircraft noise were not available on a smaller spatial scale than that of the *communes*.

In the present study, we were not able to distinguish night-time exposure to aircraft noise at the place of residence and daytime exposure to aircraft noise at the place of work. Therefore, it was not possible to disentangle their effect on mortality even if it would have been relevant as recent studies suggested that sleep disturbances due to aircraft noise could mediate the effect of aircraft noise on health especially on cardiovascular disease.[37,38]

It is worth wondering whether L_{den} was the most relevant indicator to describe the relationship between aircraft noise exposure and health effects. In health studies, it is currently recommended to consider including event-related indicators like the number of noise events or the number of events exceeding a certain LAmax level[1], especially for the night period regarding the effects of aircraft noise on sleep quality. In addition to L_{den}, it would have been interesting to consider such noise indicators in the present study to increase the impact of our results. Unfortunately, these indicators were not available in France[40]. However, such indicators will be available for 100 participants in an ongoing longitudinal study in France where acoustic measurements have been carried out for one week.

Living in the vicinity of an airport was not associated with socio-economic status in the present study: the percentages of blue collar workers and of white collar workers in the active population were very similar for the *communes* under study and for the *communes* of the whole of France, as was the proportion of the population having a certificate higher than the French high-school certificate. Moreover, the deprivation index obtained with the PCA was not correlated with L_{den}AEI (ρ = 0.12) and the interaction term between these variables was not significant in the model. Finally, the residential mobility of the study population in Paris and Lyon areas was slightly lower than the one of the French population. The residential mobility was somewhat higher in the Toulouse area but this could be explained by the fact that this area included the city of Toulouse with a high number of inhabitants, and the population of this area was also younger and more educated than in the other areas under study. Therefore, the positive associations reported between exposure to aircraft noise and mortality from cardiovascular disease, coronary heart disease and myocardial infarction do not seem to be explained by a different vulnerability of the population living near airports.

The possible adverse effect of aircraft noise on cardiovascular health could have led to a lower proportion of sensitive people among those living in the vicinity of airports. We have little information to judge whether this has occurred. However, if it has occurred, this would have resulted in an underestimation of the association between aircraft noise exposure and mortality from cardiovascular disease, coronary heart disease and myocardial infarction in the present study.

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The ecological association between average exposure to aircraft noise and mortality may be different from the individual relationship.[39] This issue has been particularly discussed in settings where there is a powerful individual risk factor for a disease, such as smoking or diet for cardiovascular disease for example. In the present study, it was not possible to collect information on confounding factors such as smoking or diet at the individual level. We used lung cancer mortality at the *commune* level as a smoking proxy because it does not exit another source providing information on smoking at both individual and aggregate levels in France. However, as living in the vicinity of an airport was not associated with socio-economic status in the present study, and as it is well-established that smoking is related to low socio-economic status, it is unlikely that the association between aircraft noise and mortality was confounded by smoking.

Results at the *commune* level may not be applicable to the individual level (ecological fallacy). However, in the next future, it will be possible to cross-check the results observed at the *commune* level in the present ecological study with those obtained at the individual level in the ongoing longitudinal study carried out in France[40] where information on confounding factors such as smoking has been collected. In addition, the possibility that the association could be due to some unmeasured confounding factors with geographical distributions similar to that of exposure to aircraft noise cannot be excluded, but we attempted to limit this bias by introducing a large set of potential confounding factors when the information was available.

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Conclusions

The present ecological study reported positive associations between weighted average exposure to aircraft noise and mortality from cardiovascular disease, coronary heart disease and myocardial infarction, even after controlling for some confounding factors, in particular air pollution. However, the number of studies investigating the relationship between exposure to aircraft noise and mortality is clearly insufficient and their results are not entirely consistent. Therefore further individual studies are necessary in order to better understand the association observed in the present paper.

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Conflicts of interest

There are no conflicts of interest.

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Table 1: Distribution of aircraft noise levels (L_{den}AEI) and of background air pollution concentrations (NO_2 and PM_{10}) for the 161 *communes* of the study area

	Numbers of *communes*	L_{den}AEI (dB(A))			NO_2 (µg.m^{-3})			PM_{10} (µg.m^{-3})		
		Mean	**Median**	**Range**	**Mean**	**Median**	**Range**	**Mean**	**Median**	**Range**
Area of study										
Paris	108	51.6	51.3	45.0 – 64.1	24.0	23.4	15.9 – 36.3	24.2	23.4	22.4 – 27.1
Lyon	31	45.3	43.4	42.0 – 55.1	16.5	16.3	12.0 – 21.9	23.9	24.0	22.3 – 26.2
Toulouse	22	45.7	44.9	42.0 – 55.8	-	-	-	-	-	-
Total [a]	161	49.6	48.9	42.0 – 64.1	22.3	21.2	12.0 – 36.3	23.9	23.6	22.3 – 27.1

[a] Only for 139 *communes* for NO_2 and PM_{10} concentrations.

Table 2: Adjusted mortality Rate Ratios (MRR) estimated in models without air pollution

	Cardiovascular disease	Coronary heart disease	Myocardial infarction	Stroke
Parameters	MRR (95% CI)	MRR (95% CI)	MRR (95% CI)	MRR (95% CI)
L_{den}AEI[a]	**1.18** (1.11 to 1.25)	**1.24** (1.12 to 1.36)	**1.28** (1.11 to 1.46)	1.08 (0.97 to 1.21)
Gender	**1.04** (1.01 to 1.07)	1.00 (0.96 to 1.05)	1.02 (0.95 to 1.08)	1.01 (0.96 to 1.06)
Age	**1.11** (1.09 to 1.13)	**1.10** (1.07 to 1.13)	**1.08** (1.04 to 1.13)	**1.15** (1.11 to 1.18)
Log(density)	**0.93** (0.90 to 0.96)	**0.94** (0.89 to 0.98)	**0.87** (0.81 to 0.93)	0.96 (0.91 to 1.02)
Deprivation index	**1.07** (1.05 to 1.10)	**1.07** (1.04 to 1.11)	**1.10** (1.05 to 1.16)	**1.08** (1.04 to 1.13)
Lung cancer mortality	1.01 (0.98 to 1.03)	1.00 (0.96 to 1.04)	0.99 (0.93 to 1.04)	1.02 (0.98 to 1.07)

L_{den}AEI, gender, age, log-density, a deprivation index and lung cancer mortality were simultaneously included in the models.

Statistically significant MRR are in bold.

[a] MRR per 10 dB(A) increase in L_{den}AEI.

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Table 3: Adjusted mortality Rate Ratios (MRR)* related to L_{den}AEI obtained in sensitivity analyses

Sensitivity analyses	Cardiovascular disease MRR (95% CI)	Coronary heart disease MRR (95% CI)	Myocardial infarction MRR (95% CI)	Stroke MRR (95% CI)
Including NO_2 [a]	**1.18** (1.10 to 1.26)	**1.23** (1.10 to 1.38)	**1.31** (1.12 to 1.53)	1.06 (0.93 to 1.21)
Including PM_{10} [a]	**1.18** (1.10 to 1.25)	**1.20** (1.09 to 1.34)	**1.26** (1.09 to 1.46)	1.08 (0.95 to 1.22)
By gender				
Male [b]	**1.29** (1.17 to 1.42)	**1.29** (1.12 to 1.49)	**1.37** (1.11 to 1.68)	1.10 (0.90 to 1.33)
Female [b]	**1.12** (1.03 to 1.23)	1.15 (0.97 to 1.37)	1.21 (0.94 to 1.55)	1.00 (0.85 to 1.19)
Including the Townsend deprivation index [c]	**1.19** (1.11 to 1.27)	**1.23** (1.10 to 1.38)	**1.31** (1.12 to 1.54)	1.06 (0.93 to 1.21)
Including adjustment for the study area [d]	**1.18** (1.10 to 1.26)	**1.26** (1.12 to 1.41)	**1.35** (1.15 to 1.59)	1.05 (0.92 to 1.20)
Including data for the Paris area only [d]	**1.11** (1.03 to 1.20)	**1.23** (1.09 to 1.40)	**1.27** (1.06 to 1.52)	1.02 (0.88 to 1.18)

Statistically significant MRR are in bold.

* MRR per 10 dB((A)) increase in L_{den}AEI.

[a] L_{den}AEI, gender, age, log-density, a deprivation index and lung cancer mortality were also included in the models.

[b] L_{den}AEI, age, log-density, a deprivation index, lung cancer mortality and average NO_2 concentration were also included in the models.

[c] L_{den}AEI, gender, age, log-density, lung cancer mortality and average NO_2 concentration were also included in the models.

[d] L_{den}AEI, gender, age, log-density, a deprivation index, lung cancer mortality and average NO_2 concentration were also included in the models.

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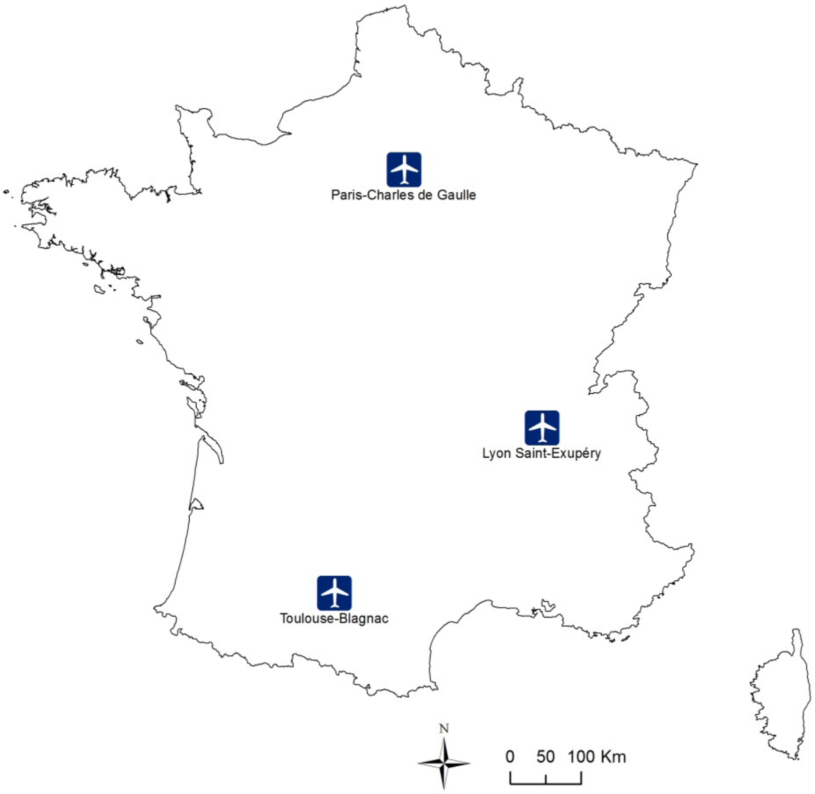

Figure 1: The three airports included in the present study

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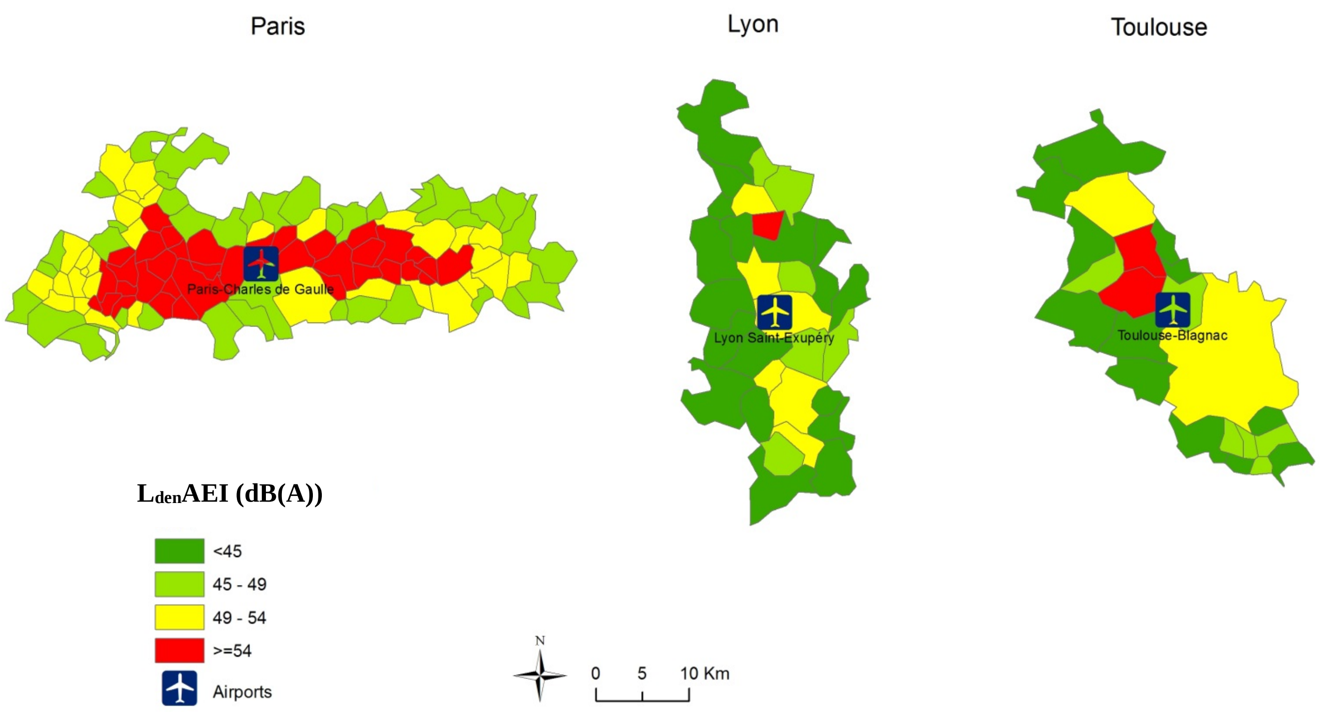

Figure 2: Distribution of L_{den}AEI in the *communes* included in the present study