Spatial relationships between residential levels of traffic noise from road and rail and air pollution in Oslo, Norway

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INTRODUCTION

Several epidemiological studies have reported associations between cardiovascular (CV) diseases and both traffic-related air pollution (Nafstad et al. 2004; Naess et al. 2007; Hoek et al. 2002) and road traffic noise (Babisch et al. 2005; Babisch 2006; de Kluizenaar et al. 2007; Selander et al. 2009). As both exposures have road traffic as their main source, air pollution may confound associations between road traffic noise and health outcomes, and vice versa, or these exposures may act together (Davies et al. 2009; Schwela et al. 2005).

So far, only a few studies have investigated the combined effects of both exposures, using a variety of indicators for road traffic noise, different air pollutants and CV outcomes (de Kluizenaar et al. 2007; Beelen et al. 2009; Selander et al. 2009). After adjusting for air pollution, the associations of noise with hypertension and CV mortality were marginally changed (de Kluizenaar et al. 2007; Beelen et al. 2009), except for removing the effect of noise on ischemic heart disease mortality (Beelen et al. 2009), and no strong effect modification were found with myocardial infarction (Selander et al. 2009). The reported correlations between noise and air pollution varied from weak to strong (Pearson's correlation coefficient (r) = 0.2-0.7). However, to our knowledge no studies have investigated the differences and similarities of the assessment approach of these pollutants in more detail, although modeled levels usually are used as exposures in epidemiological studies.

With respect to noise, it has been suggested that the levels during night-time may be most important for potential CV effects (Griefahn et al. 2008; Jarup et al. 2008). However, most epidemiological studies have only used a general noise indicator assessed at the most exposed façade (de Kluizenaar et al. 2007; Beelen et al. 2009; Selander et al. 2009), despite that many people have their bedroom facing a less exposed side of the house (Aasvang et al. 2008).

Another source of traffic is rail traffic, with a more intermittent nature than the more continuous road traffic. So far, only few recent epidemiological studies have considered health effects of rail traffic noise (Aasvang et al. 2008; Lercher et al. 2010), but no studies have reported correlations between rail traffic noise and air pollution. As potential health effects of rail traffic noise may aid in separating the effects of air pol-

lution and traffic noise, the relationship between rail traffic noise, road traffic noise and air pollution should be evaluated.

This study is part of a large project in Oslo investigating long-term CV effects of traffic-related air pollution and noise, using modelled levels of traffic noise and of air pollution at the home address of each participant in the "The Oslo Health Study" (HUBRO). We aimed at evaluating the spatial relationships between residential indicators of traffic noise and air pollution, both at the most and the least noise exposed façade. This was performed separately for road traffic and rail traffic noise.

METHODS

Site description

Oslo, which is the capital of Norway with about 600,000 inhabitants, is situated in a basin at the head of a 100 km long fjord, surrounded by hills up to 500 m above sea level (Oftedal et al. 2009). This topography can lead to large spatial variation in traffic-related air pollution. The average monthly temperature is –5 °C in January and 17 °C in July.

Study addresses

The population-based HUBRO study was conducted in 2000-2001, with 45.9 (N=18,770) participation rate (Søgaard et al. 2004). Of the study participants, 17,594 accepted to link their information to registries. Using the national identification number, Statistics Norway provided the residential history with corresponding geographical coordinates for each participant. Thereby traffic noise and air pollution were linked to each subject's home address for the study participants who did not change residence during 2006 (N=16,140). Of these, 2,025 participants lived outside of Oslo in 2006, where neither noise nor air pollution was assessed. 240 participants had address more than 10 m from a building, and were not assigned to noise. Furthermore, participants assigned to background air pollution level were excluded (n=70). We included all the participants with assessed road traffic noise (levels above zero) (N=13,764), which is called the main population.

For the comparisons with rail noise we used the subpopulation with assessed rail noise levels (N=3,475). Another subpopulation was also added, including only those subjects who were assigned air pollution levels from the receptor points (N=2,632), which represents more highly exposed subjects.

Assessment of noise

The indicators L_{den} and L_{night} (European Commision 2002) were calculated outside the most exposed façade and the least exposed façade of each study house in Oslo, separately for road traffic and for rail traffic noise. Noise from road traffic and rail traffic (railway, subway and tram) was calculated using the Nordic Prediction Method for road traffic noise (Nordic Council of Ministers 1996a) and for railway noise (Nordic Council of Ministers 1996b). These methods were implemented in the acoustical software program CadnaA, version 3.6 (Datakustik 2004), which used a geographic information system (GIS) to calculate the traffic noise levels on 5 x 5m^2 grids at 4m height (Municipality of Oslo 2007). The grid levels were interpolated at the points along the façade of each residential building, with 3 m distance between each point. All buildings and noise screens were defined as 100 % reflective and first order reflection was included in the calculations. Averages of noise measurements have shown good agreement with calculated values (Nordic Council of Ministers 1996).

Input data to CadnaA were digitalized terrain data, buildings and noise screens in 3D and ground type. Buildings were defined as building planes with maximum height of each building, and buildings demolished or built the last three years may not have been registered in the GIS. Some private noise screens were neither registered. All terrain areas were given hard ground type and completed with soft ground in areas where this was likely, such as parks, outdoor recreational areas and areas around detached houses.

Other input data to CadnaA were road traffic data (traffic counts, percentages of heavy vehicles, speed limits and diurnal distributions) from the Norwegian Public Roads Administration and the City of Oslo, and rail traffic data (frequencies, train types, train lengths and speed limits) from the National Railway Administration and from the City of Oslo (Municipality of Oslo 2007). To capture optimal quality of annual average diurnal traffic (AADT) for the road network in Oslo, all available databases of road traffic counts performed in Oslo during 2000-2006 were considered (Municipality of Oslo 2007). Only the databases with best quality of AADT were used and historical values after 2000 were interpolated to be valid for 2006, based on AADT values from 2005 for the national roads. Some of the historic traffic counts also included counts of heavy vehicles. For the rest of the road links, the City of Oslo developed a distribution of heavy vehicles based on several years of traffic counts, whereas 240 road links with a lot of bus traffic and industry were assessed separately. Diurnal distribution was based on traffic counting at 52 points on local roads in 2006, and indicates different distribution for light, medium and heavy vehicles. After evaluating whether these distributions could vary depending on road type, the same distributions may be applied on all types of local roads. For national roads, the diurnal distribution indicated 75 % road traffic in daytime, 15 % in evening and 10 % at night, which was nearly similar to the distribution used for local roads with medium traffic.

L_{den} and L_{night} were assessed for the residential houses within 500 m from national roads (roads with high traffic counts), houses within 300 m from local roads (roads with medium traffic counts), houses within 300 m from nearest railway and within 125 m from nearest subway or tram.

Assessment of air pollution

The air pollution levels in Oslo in 2006 were calculated by the EPISODE model, developed by the Norwegian Institute for Air Research (Oftedal et al. 2009; Slørdal et al. 2003). The EPISODE model is a combined three-dimensional Eulerian / Lagrangian dispersion model which calculated ground level hourly average concentrations, both as grid values and at individually placed receptor points, based on emissions, meteorology and background air pollution concentrations. The Lagrangian part of the model consists of a subgrid model for calculation of concentrations from roads with AADT above 3,000 vehicles. Depending on the AADT, this sub-grid model calculated concentrations up to 500 m from the road. Beyond this zone, the Eulerian model calculated air pollution levels using 18 (N-S) and 22 (E-W) 1 x 1 km^2 horizontal grid cells with vertical heights at 20, 30 and 150 m from ground level and up. Concentration of each km^2 was calculated by combining Eulerian and sub-grid model concentrations in 100 x 100 m^2 sub-grids and averaging over the sub-grids within each km^2 grid cell. Concentration at each receptor point was determined by the sub-grid the receptor point was located within. Further details are given in Oftedal et al. (2009) and Slørdal et al. (2003). Modelling of long-term averages was recently compared with measurements in Oslo, and the EPISODE model represented long-term levels of local outdoor air pollution reasonably well (Oftedal et al. 2009).

Hourly emissions from road traffic, domestic heating, industry and other sources were input data to EPISODE. AADT for 2006 were mainly based on The National Transport Plan (2002-2011) and updates on the main road network in 1999 from Scandiaconsult. Large parts of this road network were manually checked and corrected based on traffic counts from The Norwegian Public Roads Administration for Oslo in the period 1999-2002. In addition, parts of the most important local roads were checked and updated in collaboration with the City of Oslo, and updated traffic counts on some road segments were used for 2006. The emission factors for 2001 were taken from the National Emission Model for Road Traffic, where factors for 1997 were first scaled to 2001 (Norwegian Pollution Control Authority 1999) and then further to 2005. Diurnal time variation for 2006 was based on traffic counts conducted in 2001 on the national road E18 in Drammen, a city close to Oslo, and adjusted for some night hours. The emissions were distributed by weekday and hour of the day, capturing different variation during working days and weekends.

Emissions from domestic heating and other sources such as industry, public and private service sector, motorized equipment, ship and railway traffic were provided by Statistics Norway and were primarily based on data from 1998 (Haakonsen 2000). Emissions from wood burning as a part of domestic heating were based on consumption data from 2002 (Finstad et al. 2004) adjusted to 2005 (Slørdal et al. 2007). The emissions were distributed by week, reflecting seasonal variations, and hour of the day.

The meteorological data were measured at a central meteorological station in Oslo. These variables were measured hourly: wind speed, wind direction, temperature, stability, relative humidity and precipitation. Wind and stability data were used in the wind field model MATHEW (Sherman 1978) to create hourly gridded wind fields in accordance with the local topography. Further details are given in Oftedal et al. (2009).

The hourly background concentrations of NO_2 were based on minimum of the 24h levels measured at the regional background station Birkenes in southern Norway. The background concentrations of ozone were based on maximum hourly values measured at two regional background stations in the south of Norway.

The air pollution indicator NO_2, mainly representing traffic-related air pollution, was calculated for each km^2 grid and at 11,452 receptor points in 2006. Assigning air pollution level, residential addresses located within 30 m from a receptor point were assigned the concentration at the nearest point, whereas other addresses were assigned the concentration of the km^2 grid.

Data analysis

The residential levels of traffic noise and air pollution were presented by mean, median, standard deviation, minimum and maximum. We evaluated the spatial relationship between residential levels of traffic noise and air pollution by calculating Spearman correlation coefficient (r_s), separately for road and rail traffic noise. In determining annual concentrations of NO_2, 75 % availability was used as cut-off for a nonmissing value. The spatial relationships between the two sources of traffic noise were also evaluated.

RESULTS

Traffic noise was calculated on a finer spatial resolution than NO_2. All pollutants have a large spatial within-city variation.

Table 1: Summary statistics of road traffic noise [dB], rail traffic noise [dB] and NO_2 [µg/m^3] in 2006 in Oslo, Norway

Pollutant	Indicator	Façade	N	Mean ± SD	Median	Min – Max
Road traffic noise	L_{den}	Most exposed	13,764	55 ± 9	55	10 – 80
		Least exposed	13,764	37 ± 13	40	1 – 71
		Most exposed	*3,475	57 ± 8	57	22 – 78
		Least exposed	*3,475	39 ± 12	42	3 – 69
		Most exposed	**2,599	61 ± 8	61	34 – 80
	L_{night}	Most exposed	13,764	47 ± 9	47	3 – 71
		Least exposed	13,764	30 ± 11	32	1 – 63
		Most exposed	*3,475	49 ± 8	48	14 – 69
		Least exposed	*3,475	32 ± 11	34	3 – 61
		Most exposed	**2,599	53 ± 8	53	25 – 71
Rail traffic noise	L_{den}	Most exposed	*3,475	48 ± 11	48	12 – 73
		Least exposed	*3,475	33 ± 11	34	0 – 67
		Most exposed	**901	51 ± 11	51	23 – 73
	L_{night}	Most exposed	*3,475	40 ± 11	40	4 – 65
		Least exposed	*3,475	26 ± 10	27	0 – 58
		Most exposed	**901	43 ± 11	43	15 – 65
Air pollution	NO_2	NA	13,764	16.1 ± 9.5	13.3	1.8 – 65.2
		NA	*3,475	18.3 ± 10.4	17.6	2.0 – 65.2
		Most exposed	**2,599	25.4 ± 9.1	25.0	3.7 – 65.2
		Most exposed	**901	27.3 ± 9.0	28.2	6.1 – 65.2

*Subpopulation with assessed rail noise levels (in addition to road traffic noise)
**N for the subpopulation including only those subjects with air pollution levels from the receptor points

The L_{den} levels of road traffic noise at most exposed façade were on average 8 dB higher than L_{night}. The most exposed façade had on average 18 dB (L_{den}) and 17 dB (L_{night}) higher road traffic noise levels than the least exposed façade. In the subpopulation with assessed levels of rail noise all subjects also had assessed levels of road traffic noise (N= 3,475), which were on average 9 dB higher than the levels of rail noise. The NO_2 concentrations were higher in winter (January-April and October-December, median 15.4 µg/m^3) than summer (May-September, median 10.3 µg/m^3). In the subpopulation representing more highly exposed subjects, the traffic noise levels and the NO_2 levels were on average 6 dB (road traffic, L_{den}), 3 dB (rail traffic, L_{den}) and 9.3 µg/m^3 higher than in the main population.

Figure 1 presents the traffic noise levels for L_{den} plotted versus NO_2, both for road traffic noise and rail noise, including the higher exposed subpopulation and Spearman correlation.

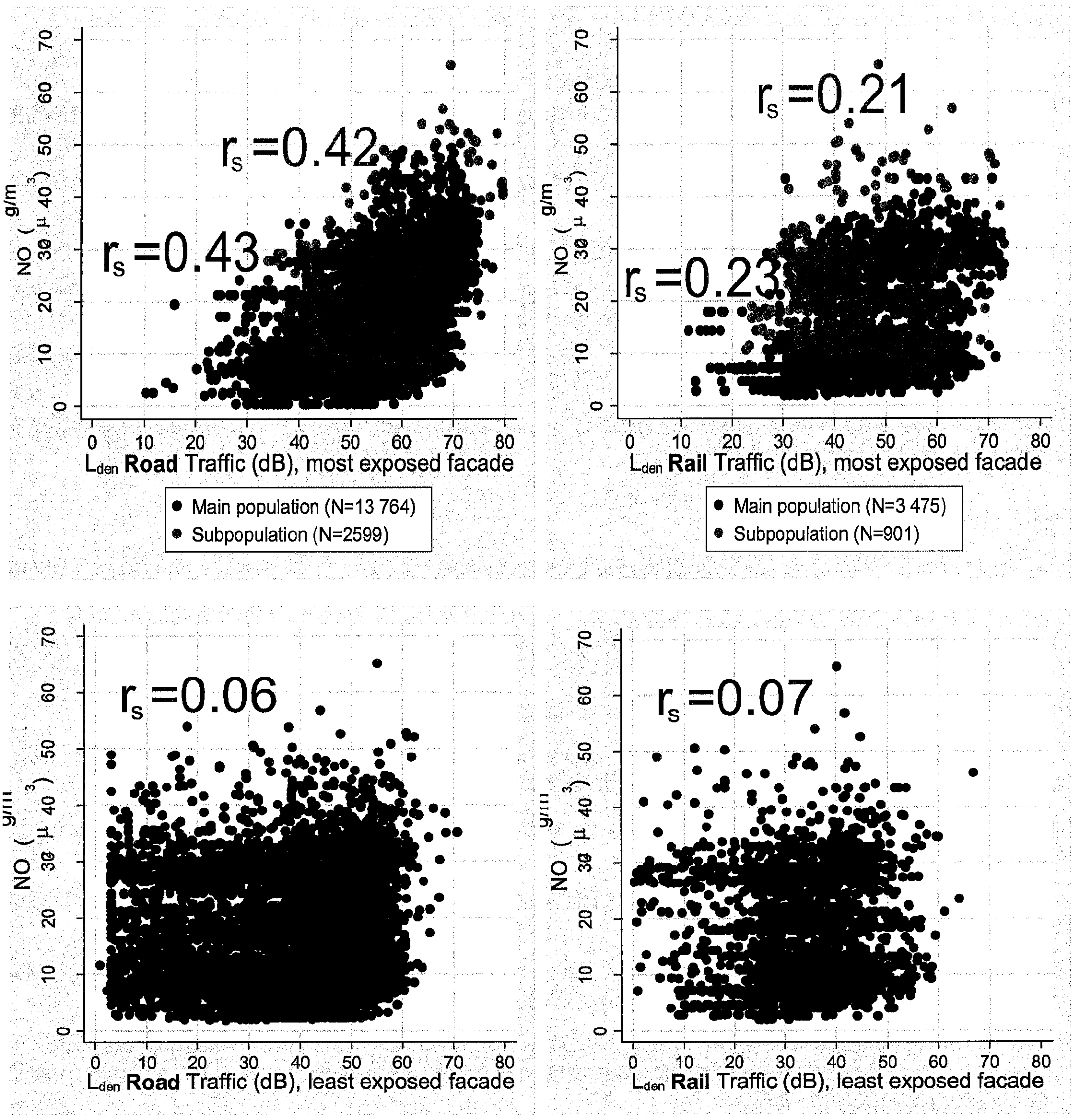

Figure 1: Road traffic noise at the most exposed façade and at the least exposed façade (L_{den}) [dB] in the first row, rail traffic noise at the most exposed façade and at the least exposed façade (L_{den}) [dB] in the second row, all plotted versus NO_2 levels [µg/m^3] in 2006 in Oslo, Norway.

The correlation between road traffic noise at most exposed façade and NO_2 was 0.42-0.43 and 0.21-0.23 between rail noise at most exposed façade and NO_2. The correlation between both sources of traffic noise at least noise exposed façade and NO_2 was lower (r_S=0.06-0.07). In the subpopulation with assessed rail noise levels the correlation between road traffic noise and NO_2 was slightly higher (r_S=0.48-0.49) than in the main population (r_S=0.42-0.43). In the subpopulation with higher exposed subjects, the correlations were unchanged (Figure 1), although slightly higher between the two sources of traffic noise (r_S=0.41-0.42) compared to the larger population (r_S=0.36-0.37). L_{den} and L_{night} had correlations of 1.00 when assessed at the same façade, but weaker correlations between noise at the least and the most exposed façade (r_S=0.26-0.28 for road traffic and r_S=0.60-0.62 for rail traffic noise).

CONCLUSIONS

Both traffic-related air pollution and noise have a large spatial variation within our urban study area. Differences in applied data on road traffic, meteorology and resolutions may have contributed to slightly reduce the calculated correlation between long-term levels of road traffic noise and NO_2. However, we found the same correlation in the higher exposed subpopulation with finer resolution of NO_2, which supports our finding. Our moderate correlation suggests a potential to separate the CV effects of traffic-related air pollution and noise in Oslo. Despite the plausible weak correlation between rail noise and NO_2, road traffic noise dominates this population, and rail noise may not contribute additionally to disentangle effects of traffic-related air pollution and noise in our urban population. The negligible correlations at the least noise exposed façade, which is often the bedroom façade, may aid in separating effects of night-time noise from air pollution.

REFERENCES

Aasvang GM, Moum T, Engdahl B (2008). Self-reported sleep disturbances due to railway noise: exposure-response relationships for nighttime equivalent and maximum noise levels. J Acoust Soc Am 124: 257-268.

Babisch W (2006). Transportation noise and cardiovascular risk: updated review and synthesis of epidemiological studies indicate that the evidence has increased. Noise & Health 8(30): 1-29.

Babisch W, Beule B, Schust M et al. (2005). Traffic noise and risk of myocardial infarction. Epidemiology 16: 33-40.

Beelen R, Hoek G, Houthuijs D et al. (2009). The joint association of air pollution and noise from road traffic with cardiovascular mortality in a cohort study. Occup Environ Med 66: 243-250.

Davies HW, Vlaanderen JJ, Henderson SB et al. (2009). Correlation between co-exposures to noise and air pollution from traffic sources. Occ Environ Med 66: 347-350.

de Kluizenaar Y, Gansevoort RT, Miedema HM et al. (2007). Hypertension and road traffic noise exposure. J Occup Environ Med 49: 484-492.

European Commision (2002). Directive of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise. Directive 2002/49/EC. Off J Eur Comm 189: 12-25.

Finstad A, Flugsrud K, Haakonsen G et al. (2004). Vedforbruk, fyringsvaner og svevestøv. Resultater fra Folke- og boligtellingen 2001. Levekårsundersøkelsen 2002 og Undersøkelse om vedforbruk og fyringsvaner i Oslo 2002, SSB-rapport 2004/5. Oslo-Kongsvinger, Norway: SSB.

Griefahn B, Bröde P, Marks A et al. (2008). Autonomic arousals related to traffic noise during sleep. Sleep 31: 569-577.

Haakonsen G (2000). Utslipp til luft i Oslo, Bergen, Drammen og Lillehammer 1991-1997. Rapport 2000/23. Oslo.

Hoek G, Brunekreef B, Goldbohm S et al. (2002). Association between mortality and indicators of traffic-related air pollution in the Netherlands: a cohort study. Lancet 360: 1203-1209.

Jarup L, Babisch W, Houthuijs D et al. (2008). Hypertension and exposure to noise near airports: the HYENA study. Environ Health Perspect 116: 329-333.

Lercher P, Brink M, Rudisser J et al. (2010). The effects of railway noise on sleep medication intake: results from the ALPNAP-study. Noise & Health 12(47): 110-119.

Municipality of Oslo (2007). Strategisk støykartlegging Oslo Forurensningsforskriftens kapittel 5 - støysituasjon for år 2006 [in Norwegian]. Oslo: Oslo kommune.

Naess O, Piro FN, Nafstad P et al. (2007). Air pollution, social deprivation, and mortality: a multilevel cohort study. Epidemiology 18: 686-694.

Nafstad P, Haheim LL, Wisloff T et al. (2004). Urban air pollution and mortality in a cohort of Norwegian men. Environ Health Perspect 112: 610-615.

Nordic Council of Ministers (1996a). Road traffic noise - the Nordic Prediction Method. TemaNord 1996: 525.

Nordic Council of Ministers (1996b). Railway noise - the Nordic Prediction Method. TemaNord 1996: 524.

Norwegian Pollution Control Authority (1999). Utslipp fra veitrafikk i Norge. SFT rapport 99:04 [In Norwegian]. Oslo, Norway.

Oftedal B, Walker SE, Gram F et al. (2009). Modelling long-term averages of local ambient air pollution in Oslo, Norway: evaluation of nitrogen dioxide, PM_{10} and $PM_{2.5}$. Int J Environ Pollut 36: 110-126.

Schwela D, Kephalopoulos S, Prasher D (2005). Confounding or aggravating factors in noise-induced health effects: air pollutants and other stressors. Noise & Health 7(28): 41-50.

Selander J, Nilsson ME, Bluhm G et al. (2009). Long-term exposure to road traffic noise and myocardial infarction. Epidemiology 20: 272-279.

Sherman CA (1978). Mass-consistent model for wind fields over complex terrain. J Appl Met 17: 312-319.

Slørdal LH, Walker SE, Solberg S (2003). The urban air dispersion model EPISODE applied in AirQUIS2003. Technical description, NILU TR 12/2003. Kjeller, Norway: Norwegian Institute for Air Research.

Slørdal LH, McInnes H, Laupsa H (2007). Evaluation of abatement measures for PM10 in Oslo and Trondheim for the year 2010, NILU OR 82/2006. Kjeller, Norway: Norwegian Institute for Air Research.

Søgaard AJ, Selmer R, Bjertness E et al. (2004). The Oslo Health Study: the impact of self-selection in a large, population-based survey. Int J Equity Health 3: 3.

Cross-sectional association between road traffic noise and hypertension in a population-based sample in Girona, Spain (REGICOR-AIR project)

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INTRODUCTION

Long-term exposure to traffic-related noise may increase blood pressure levels and induce hypertension, especially at night-time (WHO 2009). The evidence for the effects of road traffic noise on hypertension seems to be increasing, but some inconsistencies are still found in the size of the effects and in the effect modifiers involved in this association (such as age or gender) (e.g. de Kluizenaar et al. 2007; Bluhm et al. 2007; Belojevic et al. 2008; Jarup et al. 2008; Barregard et al. 2009).

Besides, long-term exposure to traffic-related air pollution has been also associated with cardiovascular health (HEI 2010). There could be some interrelated biological pathways of long-term exposure to road traffic noise and air pollution leading to common cardiovascular endpoints. Therefore, traffic-related air pollution may confound the cardiovascular effects of road traffic noise in the long-term (Foraster et al. 2011). However, to our knowledge, few studies analyzing hypertension could consider air pollution (de Kluizenaar et al. 2007; Jarup et al. 2008).

We evaluated the cross-sectional association between outdoor residential modeled estimates of road traffic equivalent noise levels (L_{night} and L_{24h}) and hypertension, adjusting for outdoor long-term modeled estimates of traffic-related air pollution in the city of Girona, north-eastern Spain, within the REGICOR-AIR project. We also evaluated the association by age groups and gender.

METHODS

We evaluated 3,480 baseline participants (35-83 years old) corresponding to the population-based HERMES cohort (years 2003-2005). Trained nurses administered questionnaires on socio-demographic and lifestyle characteristics and collected information on general and cardiovascular health. They also took blood pressure measurements following the standard procedures of the project, based on the Joint National Committee VII.