Acoustics'08 Paris
June 29-July 4, 2008
www.acoustics08-paris.org

Associations between road traffic noise level, road traffic noise annoyance and high blood pressure in the HYENA study

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The HYENA study is a multi-centred study regarding the effects of aircraft noise and road traffic noise on blood pressure (BP) which was funded by the European Community. Study subjects were 4,861 males and females aged between 45 and 70 years, who had lived for at least 5 years in the vicinity of any of six major European airports. Aircraft noise contours and road traffic noise levels were modelled using the Integrated Noise Model (INM) and national calculation methods. The noise levels were linked to each participant's home address using graphical information systems. Noise annoyance was assessed using the 11-point ICBEN scale. High blood pressure was determined by measurements of systolic and diastolic blood pressure, anti-hypertensive medication and self-reported doctor diagnosed hypertension. The road traffic noise level ($L_{Aeq,24hr}$) was significantly associated with high blood pressure, but not the annoyance due to road traffic noise. Subjects who had lived for many years in their present home had a higher traffic noise-related risk of hypertension. The association between road traffic noise level and high blood pressure was stronger in highly annoyed subjects.

1 Introduction

Road traffic noise is the major source of noise in our communities. It causes annoyance, sleep disturbance, stress reactions. In the long run, road traffic noise is a risk factor for cardiovascular diseases in chronically exposed subjects, including high blood pressure and ischaemic heart disease. Both, the objective exposure (noise level) and the subjective perception of the noise (annoyance) are inter-related and appear on the pathway from noise exposure to clinical disorders (disease).

2 The HYENA study

The HYENA study (HYENA = HYpertension and Exposure to Noise near Airports) is a large-scale multi-centred study carried out simultaneously in 6 European countries to assess the relationship between aircraft noise and road traffic noise on the one hand, and the prevalence of noise annoyance and high blood pressure on the other. It was funded by a grant from the European Commission within the 5th Framework Programme (grant QLRT-2001-02501). The study population included 4861 people (2404 men and 2467 women) aged between 45 and 70 years at the time of interview, and who had been living for at least 5 years, near one of the six major European airports (London Heathrow (GB), Berlin Tegel (D), Amsterdam Schiphol (NL), Stockholm Arlanda (S), Milan Malpensa (I) and Athens Elephterios Venizelos (GR)). In Stockholm, also the population living near the City Airport (Bromma) was included to increase the number of exposed subjects. Field work was carried out during the years 2003-2005. More details were given elsewhere [1, 2]. The focus in the following is on road traffic noise only.

3 Methods

3.1 Road traffic noise level

Road traffic noise assessment was based on available noise data (reference year 2002) according to the national assessment methods (GB: *Calculation of Road Traffic Noise*; D, I: *Richtlinien für den Lärmschutz an Straßen*; GR, NL: *Standaard Rekenen Meetvoorschrift (SRM)*; S: *Nordic Prediction Method* and the '*Good Practice Guide for Strategic Noise Mapping*' [2]. Modelled noise exposure levels were linked to each participant's home address using geographic information systems (GIS) technique. $L_{Aeq,24hr}$ and L_{night} were derived from these data, and thus highly correlated (overall $r_p = 0.97$). The calculation was made with reference to the nearest facades of the houses. To minimize the impact of inaccuracies on the noise levels at the lower end, a cut-off value of 45 dB for $L_{Aeq,24hr}$ was introduced.

3.2 Road noise annoyance

During the home visits personal interviews were carried out. The standardized questionnaire consisted of questions regarding health status, socio-demographic, lifestyle and behavioral factors, annoyance and personality factors. Noise annoyance was assessed using the non-verbal 11-point ICBEN scale, because verbal translations were only available in English, German and Dutch [3]. A distinction was made between source-specific noise annoyances during the day and the night.

3.3 High blood pressure

Blood pressure (BP) measurements were carried during the home visits under standardized conditions using validated automated blood pressure instruments (e. g. OMRON M5-1). Subjects were classified as hypertensive according to the WHO criterion (systolic BP >= 140 mmHg or diastolic BP >= 90 mmHg), or the prevalence of doctor-diagnosed hypertension ("Have you ever been diagnosed as having high blood pressure?"), or antihypertensive medication in conjunction with a diagnosis of hypertension (ATC-codes C02, C03, C07, C08, C09) [2,4].

3.4 Confounding factors and effect modifiers

A number of potential confounders were assessed in the HYENA study. The following were used for adjustment in the statistical analyses country, age, gender, years of education, alcohol intake, body mass index, physical activity. Smoking and salt intake were also assessed but did not show a significant association with blood pressure. As part of the interview potential effect modifiers were assessed. These included personality and behavioral factors were assessed, including noise sensitivity, belief in authorities and attitude towards the airport [3]. Furthermore, the frequency of usage of noise reducing remedies (during the day and during the night) was assessed (e.g. ear plugs, closing windows, closing window shutters, other, dichotomous variable (if any coding =1, otherwise coding =0). These variables were treated as covariates in the present data analyses. Finally, subgroup analyses were carried out with respect to years of residence in the present home, room orientation (living room or bedroom facing the street: "Can you see the street that is your postal address from your window?" – yes/no), living room and bedroom window opening habits ("When you are in the rooms, do you usually have the windows open or closed?" – winter/summer, yes/no) and annoyance ('highly' annoyed = categories 8,9,10 on the 11 point scale).

4 Results

4.1 Road traffic noise level

For the main analyses the combined BP indicator and the road noise indicators $L_{Aeq,24hr}$ (range: ≤45-77 dB(A), 10^{th}-90^{th} percentile: 45-65 dB(A)) and L_{night} (range: ≤35-70 dB(A), 10^{th}-90^{th} percentile: 35-59 dB(A)) were used. Multiple logistic regression analyses controlling for aircraft noise and all confounders revealed a significant odds ratio (OR) of 1.10 (95% confidence interval CI = 1.00-1.20, p = 0.044) per 10 dB(A) increase in noise level (LAeq,24h) [2]. The result is shown in Table 1 (model 1). When additionally the effect modifiers were considered as covariates, the result was similar (model 2). Only coping style had a slight impact on hypertension (lower risk with better coping, p = 0.086). The association between road traffic noise and hypertension was stronger when only subjects were considered that had been living for more than 15 years in their present home (OR = 1.16, p = 0.013, n = 2827, model 3). The association was also stronger for subjects that were 'highly' annoyed by road traffic noise during the day (OR = 1.33, p = 0.034, n = 527, model 5) compared to less annoyed subjects (OR = 1.09, p = 0.105, n = 4284, model 4).

When $L_{Aeq,24hr}$ was replaced by L_{night} in the models, similar results were found, because both noise indicators were highly correlated (r_p = 0.97). The overall effect was OR = 1.09 (CI = 1.01-1.18, p = 0.034) per 10 dB(A) increase in noise level (models 13, 14). The association was stronger for subjects that were 'highly' annoyed by road traffic noise during the night, but statistically not significant due to small numbers (OR = 1.14, p = 0.456, n = 322, model 16) compared to less annoyed subjects (OR = 1.09, p = 0.039, n = 4531, model 15).

When the sample was stratified according to window opening habits (subjects that had the windows usually closed throughout winter and summer vs. others) significant associations between the noise levels $L_{Aeq,24hr}$ (OR = 1.23, p = 0.005, n = 1886, model 7) and L_{night} (OR = 1.31, p = 0.002, n = 1259, model 18) were only found for open window conditions. For closed windows the odds ratios were OR = 1.06 and OR = 1.02, respectively (models 6, 17).

Unexpected results were found with respect to room orientation. The associations between road traffic noise and hypertension were stronger and significant for subjects whose living room (n = 1511), bedroom (n = 2279) or both rooms (n = 969) were not facing the street (models 8, 19, 10). On the other hand, only marginal non-significant odds ratios were found for subjects whose rooms (n = 3267, 2512, 1977, respectively) were facing the street (models 9, 20, 12).

These unexpected results were not found in the Berlin sample. There, the association was stronger for subjects with the living room facing the street (OR = 1.41, p = 0.006, n = 499, model 22) than for subjects with the living room not facing the street (OR = 1.05, p = 0.718, n = 473, model 21). Furthermore, when the Berlin sample was stratified into three groups (bed- and living room not facing the street vs. either bedroom or living room facing the street vs. both rooms facing the street), a steady increase of the effect estimate was found with decreasing shielding of rooms: OR = 1.13, p = 0.469, n = 304 vs. OR = 1.17, p = 0.249, n = 391 vs. OR =1.50, p = 0.026, n = 277 (models 23, 24, 25).

The study area around the Berlin airport was different from the other study areas. Only Stockholm Bromma and Berlin Tegel were located in the cities. Type of housing along the noisy streets in Berlin was largely characterized by terraced 4-5 storey buildings in long rows along the streets, which are effective sound barriers with respective to the exposure of the backside of the houses. Not many people lived in whole houses. Type of housing was assessed in the HYENA study by questionnaire. 11.8, 85.6, 5.6, 30.2, 0.5, 17.4 percent of the subjects from the UK, Germany, Netherlands, Sweden, Greece, Italy lived in flats, maisonettes or apartments, while the others lived in whole houses or bungalows. When the analysis was stratified according to type of housing, a larger effect estimate was found for subjects that lived in flats and apartments (OR = 1.26, p = 0.004, n = 1389, model 27) than for subjects that lived in whole houses or bungalows (OR = 1.03, p = 0.637, n = 3459, model 26).

4.2 Road traffic noise annoyance

Table 2 shows the results of the associations between annoyances during the day (range: 0-10 units, 10^{th}-90^{th} percentile: 0-8 units) and during the night (range: 0-10 units, 10^{th}-90^{th} percentile: 0-6 units) due to road traffic noise on high blood pressure. No significant effects were found in the main analyses. The odds ratio were OR = 1.01 and OR = 1.00 per unit on the 11-point scale with respect to traffic noise during the day (models 28, 29) and the night (models 33, 34), respectively. Restriction to subjects that had lived for more than 15 years in their present homes revealed similar results (models 30, 35). Stratification of the analyses with respect to the orientation of rooms had no significant impact on the results – neither when orientation of the living room and the annoyance during the day were considered (models 31, 32), nor when the orientation of the bedroom and the annoyance during the night were considered (models 36, 37).

4.3 Associations between road traffic noise level and road traffic noise annoyance

The results shown in the previous chapters suggested that the road noise level was a risk factor for high blood pressure, but not noise annoyance. Noise annoyance, however, was an effect modifier of the relationship between noise level and high blood pressure. Clear exposure-response relationships were found between the noise level and the noise annoyance [3]. Table 3 shows the regression coefficients (B) of the association derived from multiple linear regression analyses, using the same sets of covariates as for the blood pressure related analyses. An increase of 10 dB(A) in the noise level ($L_{Aeq,24hr}$) was associated with an increase of 1.6 units on the annoyance scale (B = 1.56, CI = 1.45-1.68, p = 0.000) when only the confounders were considered in the model. When additionally the effect modifiers were considered as covariates in the model, the regression coefficient was B = 1.49. With respect to L_{night} the regression coefficients were B = 0.88 (CI = 0.79-0.97, p = 0.000) and B = 0.84, respectively. The inclusion of the effect modifiers did not much change the relationship between noise level and noise annoyance. However, noise sensitivity (p = 0.000), coping style (p = 0.001), use of noise reducing remedies during the day (p = 0.000), and annoyance due to aircraft noise during the day (p = 0.000) were all positively correlated with the road traffic noise annoyance during the day. Noise sensitivity (p = 0.000), coping style (p = 0.049), use of noise reducing remedies during the night (p = 0.000), and noise annoyance due to aircraft noise during the night (p = 0.000) were all positively correlated with the road traffic noise annoyance during the night.

The relationships between noise level and noise annoyance were slightly stronger if the subjects had rooms facing the street (Table 3). For subjects whose living room was facing the street the regression coefficient for the relationship between $L_{Aeq,24hr}$ and traffic noise annoyance during the day was B = 1.62 (CI = 1.48-1.77, p = 0.000). When the living room was not facing the street the coefficient was B = 1.41 (CI = 1.22-1.61, p = 0.000). With respect to the relationship between L_{night} and annoyance during the night due to noise in the bedroom, the correlation coefficients were B = 1.01 (CI = 0.87-1.14) and B = 0.74 (CI = 0.62-0.86), respectively.

5 Conclusions

Long-term- exposure to high levels of road traffic noise was found to be a risk factor for high blood pressure in the HYENA study. Annoyance due to road traffic noise was an independent outcome of the noise exposure. It was not significantly associated with hypertension, as defined by a combination of different criteria of high blood pressure (BP measurements, antihypertensive drugs and self-reported doctor diagnosis). The data, however, suggested that noise annoyance was an effect modifier of the association between the noise level and hypertension. Length of residence and open windows were also associated with larger odds ratios due to road traffic noise. Puzzling results were found with respect to room orientation, which needs further elaboration. Unknown factors in the different study areas, including type of housing, level of urbanization, effectiveness of shielding, distance from the road, background noise could be explanatory factors.

Model	Road Noise Indicator	Covariates	Odds Ratio OR per 10 dB(A)	95% Confidence Interval CI	Significance p-value
1	$L_{Aeq,24hr}$	Aircraft noise, confounders	1.097	1.003-1.201	0.044
2	$L_{Aeq,24hr}$	Aircraft noise, confounders, effect modifiers	1.099	1.003-1.205	0.043
3	$L_{Aeq,24hr}$	Aircraft noise, confounders Subgroup: years in present home >15	1.158	1.031-1.301	0.013
4	$L_{Aeq,24hr}$	Aircraft noise, confounders Subgroup: not 'highly annoyed'	1.088	0.983-1.204	0.105
5	$L_{Aeq,24hr}$	Aircraft noise, confounders Subgroup: 'highly annoyed'	1.332	1.022-1.736	0.034
6	$L_{Aeq,24hr}$	Aircraft noise, confounders Subgroup: living room windows closed	1.062	0.891-1.266	0.503
7	$L_{Aeq,24hr}$	Aircraft noise, confounders Subgroup: living room windows open	1.234	1.064-1.431	0.005
8	$L_{Aeq,24hr}$	Aircraft noise, confounders Subgroup: living room not facing the street	1.301	1.112-1.523	0.001
9	$L_{Aeq,24hr}$	Aircraft noise, confounders Subgroup: living room facing the street	1.032	0.922-1.155	0.582
10	$L_{Aeq,24hr}$	Aircraft noise, confounders Subgroup: living room and bedroom not facing the street	1.332	1.095-1.620	0.004

11	$L_{Aeq,24hr}$	Aircraft noise, confounders Subgroup: either living room or bedroom facing the street	1.122	0.971-1.297	0.120
12	$L_{Aeq,24hr}$	Aircraft noise, confounders Subgroup: 'living room and bedroom facing the street	0.987	0.949-1.148	0.866
13	L_{night}	Aircraft noise, confounders	1.088	1.007-1.177	0.034
14	L_{night}	Aircraft noise, confounders, effect modifiers	1.093	1.010-1.183	0.028
15	L_{night}	Aircraft noise, confounders Subgroup: not 'highly annoyed'	1.090	1.004-1.184	0.039
16	L_{night}	Aircraft noise, confounders Subgroup: 'highly annoyed'	1.141	0.807-1.612	0.456
17	L_{night}	Aircraft noise, confounders Subgroup: bedroom windows closed	1.021	0.913-1.142	0.716
18	L_{night}	Aircraft noise, confounders Subgroup: bedroom windows open	1.311	1.106-1.555	0.002
19	L_{night}	Aircraft noise, confounders Subgroup: bedroom not facing the street	1.155	1.035-1.289	0.107
20	L_{night}	Aircraft noise, confounders Subgroup: bedroom facing the street	1.039	0.928-1.164	0.505
21	$L_{Aeq,24hr}$	Aircraft noise, confounders Subgroup: 'Berlin'; living room not facing the street	1.048	0.814-1.348	0.718
22	$L_{Aeq,24hr}$	Aircraft noise, confounders Subgroup: 'Berlin'; living room facing the street	1.405	1.101-1.791	0.006
23	$L_{Aeq,24hr}$	Aircraft noise, confounders Subgroup: 'Berlin'; living room and bedroom not facing the street	1.127	0.816-1.556	0.469
24	$L_{Aeq,24hr}$	Aircraft noise, confounders Subgroup: 'Berlin'; either living room or bedroom facing the street	1.174	0.894-1.543	0.249
25	$L_{Aeq,24hr}$	Aircraft noise, confounders Subgroup: 'Berlin'; living room and bedroom facing the street	1.498	1.048-2.139	0.026
26	$L_{Aeq,24hr}$	Aircraft noise, confounders Subgroup: whole house, bungalow or mobile home	1.028	0.917-1.152	0.637
27	$L_{Aeq,24hr}$	Aircraft noise, confounders Subgroup: flat, maisonette or apartment	1.258	1.078-1.468	0.004

Table 1. Associations between road traffic noise level and high blood pressure

Model	Road Noise Annoyance	Covariates	Odds Ratio OR per Unit (11 point scale)	95% Confidence Interval CI	Significance p-value
28	Day	Aircraft noise annoyance, confounders	1.008	0.986-1.030	0.485
29	Day	Aircraft noise annoyance, confounders, effect modifiers	1.012	0.990-1.035	0.290
30	Day	Aircraft noise annoyance, confounders Subgroup: years in present home >15	1.001	0.973-1.030	0.936
31	Day	Aircraft noise annoyance, confounders Subgroup: living room not facing the street	1.005	0.966-1.046	0.809

32	Day	Aircraft noise annoyance, confounders Subgroup: living room facing the street	1.011	0.984-1.038	0.427
33	Night	Aircraft noise annoyance, confounders	0.996	0.971-1.021	0.755
34	Night	Aircraft noise annoyance, confounders, effect modifiers	1.002	0.977-1.028	0.862
35	Night	Aircraft noise annoyance, confounders Subgroup: years in present home >15	1.004	0.972-1.037	0.821
36	Night	Aircraft noise annoyance, confounders Subgroup: bedroom not facing the street	0.996	0.958-1.036	0.845
37	Night	Aircraft noise annoyance, confounders Subgroup: bedroom facing the street	0.994	0.961-1.028	0.728

Table 2. Associations between road traffic noise annoyance and high blood pressure

Road Noise Indicator	Road Noise Annoyance	Covariates	Regression Coefficient B per 10 dB(A)	95% Confidence Interval CI	Significance p-value
$L_{Aeq,24hr}$	Day	Confounders	1.56	1.45-1.68	0.000
$L_{Aeq,24hr}$	Day	Aircraft noise annoyance, confounders, effect modifiers	1.49	1.38-1.60	0.000
$L_{Aeq,24hr}$	Day	Confounders Subgroup: living room not facing the street	1.41	1.22-1.61	0.000
$L_{Aeq,24hr}$	Day	Aircraft noise annoyance, confounders, effect modifiers Subgroup: living room facing the street	1.62	1.48-1.77	0.000
L_{night}	Night	Confounders	0.88	0.79-0.97	0.000
L_{night}	Night	Aircraft noise annoyance, confounders, effect modifiers	0.83	0.74-0.91	0.000
L_{night}	Night	Confounders Subgroup: bedroom not facing the street	0.74	0.62-0.86	0.000
L_{night}	Night	Aircraft noise annoyance, confounders, effect modifiers Subgroup:bedroom facing the street	1.01	0.87-1.14	0.000

Table 3. Associations between road traffic noise level and road traffic noise annoyance

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