



# ENVIRONMENTAL HEALTH PERSPECTIVES

## Hypertension and Exposure to Noise near Airports - the HYENA study

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Abbreviations and definitions:

BMI	body mass index
BP	blood pressure
ECAC	European Civil Aviation Conference
EGRET	Epidemiology, Graphics, Estimation, and Testing
HT	hypertension
IATA	International Air Transport Association
$L_{Aeq,T}$	indicators of exposure; A-weighted equivalent continuous noise level over T hours.

$L_{Aeq,16h}$	(day defined as the hours between 07 and 23 or between 06 and 22 hour depending on the local definition)
$L_{night}$	(night being defined as the hours between 23 and 07 or between 22 and 06 hour)
SAS	Statistical Analysis Software

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## **Abstract**

### **Background**

An increasing number of people are exposed to aircraft and road traffic noise. Hypertension is an important risk factor for cardiovascular disease and even a small contribution in risk from environmental factors may have a major impact on public health. The HYENA study aimed to assess the relations between noise from aircraft or road traffic near airports and the risk of hypertension.

**Methods.** We measured blood pressure and collected data on health, socio-economic and life-style factors, including diet and physical activity, via questionnaire at home visits for 4,861 persons aged 45 to 70, who had lived at least five years near any of six major European airports. Noise exposure was assessed using detailed models with a resolution of 1dB (5dB for UK road traffic noise), and a spatial resolution of 250 x 250m for aircraft and 10 x 10m for road traffic noise.

**Results.** We found significant exposure-response relationships between night-time aircraft as well as average daily road traffic noise exposure and risk of hypertension after adjustment for major confounders. For night-time aircraft noise, a 10dB increase in exposure was associated with an odds ratio of 1.14 (95% confidence interval: 1.01-1.29). The exposure-response relationships were similar for road traffic noise and stronger for men with an odds ratio of 1.54 (95% CI: 0.99-2.40) in the highest exposure category (>65dB);( $p_{\text{trend}} = 0.008$ ).

**Conclusions.** Our results indicate excess risks of hypertension related to long term noise exposure, primarily for night-time aircraft noise and daily average road traffic noise.

## **Introduction**

Air traffic continues to increase world-wide, and recent forecasts by the International Air Transport Association (IATA) predict an average annual growth in the number of air passengers of 4.3% until 2015. As a consequence the airspace is becoming more crowded, in particular in the vicinity of airports, and pollution increases from noise and aircraft exhaust emissions as well as from the associated road traffic.

Hypertension is a major risk factor for coronary heart disease and stroke (Stamler 1992). Recent studies indicate that noise exposure may cause hypertension, but few investigators have studied health effects associated with exposure to aircraft noise (Babisch 2006; van Kempen et al. 2002). Studies carried out around Schiphol airport in the 1970's showed excess risks of hypertension and other cardiovascular diseases in subjects exposed to high levels of aircraft noise (Knipschild 1977). In a recent study around the same airport only a slight increase (RR=1.2) of self-reported use of cardiovascular drugs was found (Franssen et al. 2004). A Swedish cross-sectional study indicated an exposure-response relation between residential aircraft noise exposure and self-reported (diagnosed by a physician) hypertension (Rosenlund et al. 2001). In a Japanese study near a military airbase, there was an exposure-response relationship between aircraft noise and prevalence of hypertension (Matsui et al. 2004).

Noise from road traffic has also been associated with self-reported doctor diagnosed hypertension (Bluhm et al. 2007) or measured high blood pressure (Herbold et al. 1989). However, negative results have also been reported (Yoshida et al. 1997). It has been

hypothesized that persistent exposure to environmental noise could result in permanent vascular changes, with increased blood pressure and ischemic heart disease as potential outcomes (Stansfeld and Matheson 2003).

The overall evidence suggests that a weak association may exist between long-term noise exposure and hypertension (Babisch 2000; Berglund and Lindvall 1995; Berglund et al. 1999).

The objective of the HYENA study was to assess the relationships between exposure to noise generated by aircraft and road traffic near airports and the risk of hypertension.

## **Methods**

The study complies with the Declaration of Helsinki and was approved by ethical committees in all participating centres. Informed written consent was given by all participants prior to study commencement.

### ***Participants***

The study population included persons 45-70 years old at the time of interview, with a minimum length of residence of five years, living near one of six major European airports (London Heathrow, Berlin Tegel, Amsterdam Schiphol, Stockholm Arlanda, Milan Malpensa and Athens Eleftherios Venizelos airport). In Stockholm, the population living near City Airport (Bromma) was also included to increase the number of exposed subjects. To maximise exposure contrast, we used a stratified sample of the population



based on noise exposure levels. The selection process created exposure contrast to aircraft noise and road traffic noise within countries, ensuring that sufficient numbers of inhabitants in the appropriate age range had expected exposures  $> 60$  dB(A) and  $< 50$  dB(A). For the initial selection process of the study population, we used recent aircraft noise contours that were available for all but the new Athens airport, where the information was limited, but we were able to use predicted noise contours calculated in the planning process. We used local noise data to obtain road traffic exposure classification of locations and populations. If such data were unavailable, two simplified methods derived from more complex models were applied. Further details of the selection process can be found elsewhere (Jarup et al. 2005).

### ***Blood pressure***

We used validated and automated blood pressure instruments to minimize observer errors, commonly occurring in the previously used conventional sphygmomanometry (O'Brien et al. 2001). Such instruments are well established in clinical research and are increasing in importance in occupational and environmental medicine (Staessen et al. 2000). Specially trained staff assessed BP three times at home visits; the first measurement was recorded in the beginning of the interview, after five minutes' rest, a second BP measurement was recorded after a further one minute's rest in accordance with recommendations of the American Heart Association (Pickering et al. 2005). A third BP reading was taken after the interview (circa one hour) as a validity control. The mean of the first two readings was used to define BP for the subsequent analyses. Using the mean of all three BP readings did not change the results. All BP assessments were

performed with the participant in a sitting position. Home visits were distributed over the day as far as feasible, to account for diurnal variations in BP.

Hypertension was defined according to the World Health Organization (WHO 1999, WHO 2003) i.e. a systolic blood pressure  $\geq 140$  or a diastolic BP  $\geq 90$ . In the epidemiological analyses, we combined the measurements with information on diagnoses of hypertensive disease and medication. The study definition of hypertension included individuals who either had BP levels above the WHO cut-off points or a diagnosis of HT (by a physician) in conjunction with use of antihypertensive medication, as reported in the interview questionnaire.

### ***Confounders***

We included variables a priori considered to be the major potential confounders, being risk factors for hypertension as well as possibly associated with noise exposure. In the adjustment for confounders, country and gender were included as categorized variables; age was included as a continuous variable. We defined alcohol intake as a continuous variable recorded as number of units (1 unit = 10 ml of pure ethanol) consumed per week. Body mass index (BMI=weight divided by height squared) was also included as a continuous variable, whereas the level of physical activity was estimated in three categories of exercise by duration only (less than once a week, 1-3 times a week and more than 3 times a week). Education was coded as quartiles of number of years in education, standardized by country means in order to account for differences in education systems between countries. Smoking is a well known risk factor for heart disease, but not

for hypertension, and thus, smoking was not included in the model, as explained further in the Discussion.

### ***Exposure assessment***

The Integrated Noise Model (Gulding et al. 1999) served as standard model for aircraft noise and was used in the study areas of Germany, The Netherlands, Sweden, Italy and Greece to calculate the aircraft noise levels. In the UK the model Ancon (Ollerhead et al. 1999) was applied; this model fulfils the requirements of the European Civil Aviation Conference (ECAC 1997).

For road traffic noise the models used locally were more tailored to the available input data than a centrally prescribed model. In the UK *Calculation of Road Traffic Noise* (CRTN 1988), in Germany and Italy *Richtlinien für den Lärmschutz an Straßen* (RLS90 1990), in Greece and in The Netherlands *Standaard Reken- en Meetvoorschrift (SRM)* (RMW 2002) and in Sweden the *Nordic Prediction Method* (Bendtsen 1999) was applied. The *Good Practice Guide for Strategic Noise Mapping* (European Commission 2006) was used to assess the quality of the input data. The most frequently reported accuracy per input class was 1 dB with exception of building height for which less accurate data was obtainable. The spatial resolution (grid size) was 250 x 250m for aircraft and 10 x 10m for road traffic noise.

Noise levels for separate periods of the day were modelled for 2002; this year was assumed to be representative for the five-year period preceding the health status assessment (Jarup et al. 2005). Modelled noise exposure levels were linked to each

participant's home address using geographic information systems (GIS) technique. For both aircraft and road traffic noise the levels had a 1 dB resolution, except for the UK where only 5 dB classes for road traffic noise could be procured. The midpoints of these classes were chosen for the analyses using continuous exposure data.

To assess the effect of noise on hypertension, we used  $L_{Aeq,T}$  as indicators of exposure as recommended by the WHO (1999).  $L_{Aeq,T}$  is the A-weighted equivalent continuous noise level over T hours. For aircraft noise, the indicators  $L_{Aeq,16h}$  (day defined as the hours between 07 and 23 or between 06 and 22 hour depending on the local definition) and  $L_{night}$  (night being defined as the hours between 23 and 07 or between 22 and 06 hour) were used to differentiate between the effects of daytime and night-time exposure.

In most countries only aggregated 24-hour data on the intensity of road traffic were available.  $L_{Aeq,24h}$  and  $L_{night}$  are derived from these data, and thus highly correlated (overall  $r=0.97$ ). Consequently, no distinction could be made between the relative effects on hypertension of road traffic noise exposure during the night or during the day.

The accuracy of the noise modeling decreases at lower levels. Input data such as traffic intensities can be so low that relatively small deviations from the actual flows may have large effects on the noise level. To minimize the impact of such inaccuracies on the noise levels, a cut-off value was introduced in several countries at the lower end of the noise levels, based on a local assessment of the accuracy of the input data and noise model characteristics. Since the cut-off value differed between countries, the highest local cut-off value was applied to all data. Noise level values below this cut-off value were

assigned the level of the cut-off value. For aircraft noise the cut-off level was for  $L_{Aeq,16h}$  35 and for  $L_{night}$  30 dB. For road traffic noise the cut-off level was 45 dB for  $L_{Aeq,24h}$

### ***Statistical analysis***

Standard statistical methods were applied using standard software packages (e.g. SAS, EGRET). Logistic regression models were used with the presence of hypertension as the outcome variable; exposure variables (categorical and continuous) and confounders as covariates. Confidence intervals (95 per cent) were calculated for each effect estimate. Analyses in 5dB categories suggested approximately linear relationships, and thus we used continuous data in the final analyses to increase the statistical power.

To assess the importance of heterogeneity between study sites, we also performed meta-analyses of country-specific analyses, using BioStat Comprehensive Meta-Analysis software, using a fixed-effects model.

## **Results**

A total of 4,861 persons (2,404 men and 2,457 women) between 45 and 70 years old at the time of interview participated in the study. Participation rates differed between the countries, from circa 30 % in Germany, Italy and the UK, to 46 % in the Netherlands, 56 % in Greece and 78% in Sweden. Participation rates did not differ much between the different noise exposure categories. Overall, response rates were 39, 45 and 45 % for aircraft noise categories <50, 50-<65 and 65+ dBA respectively. The corresponding response rates for road traffic noise were 51, 42 and 37%.

No gender differences were found between responders and non-responders, and a short non-response questionnaire distributed to a sample of non-responders indicated no obvious differences in prevalence of self-reported hypertension between non-responders and participants. A minimum of 10% of the questionnaire data was double-entered in all countries. The data entry errors varied between countries, but were generally low (0.13% to 1.54%).

The gender and age adjusted (to the European standard population) prevalence of hypertension was 48.8% in the UK, 54.6% in Germany, 51.9% in the Netherlands, 52.0% in Sweden, 57.0% in Greece and 52.1% in Italy.

Table 1 shows the results for the main potential confounders. Country (versus UK as the baseline), physical activity (duration of exercise) and education (quartiles) were overall statistically significant ( $p=0.028$ ,  $p=0.031$ , and  $p=0.044$  respectively).

Figure 1 shows the odds ratios for hypertension in relation to aircraft noise during the day ( $L_{Aeq,16h}$ ) and during the night ( $L_{night}$ ). A rise in odds ratio with increasing exposure is indicated primarily for night-time noise. There were no differences in risk between men and women.

Figure 2 shows the odds ratios for hypertension in men and women in relation to daily average road traffic noise exposure ( $L_{Aeq,24h}$ ). There was an increase in risk for men related to increasing exposure, but no such trend was found for women. The difference in trend between genders is statistically significant ( $p=0.004$ ).

Table 2 shows the odds ratios for hypertension related to aircraft and road traffic noise using continuous variables after adjustment for the other noise exposure indicators, odds ratios showing the risk per 10 dB increase in noise exposure. The trends for night-time exposure to aircraft and average 24h exposure to road traffic were both statistically significant whereas 16h day-time average aircraft noise exposure was not.

We also explored the differences in risks between countries in country specific analyses, assessing heterogeneity and performing a meta-analysis using a fixed effects model. As can be seen in figure 3 there was no obvious heterogeneity between countries for aircraft noise, and thus pooling the data to gain statistical power is justified. For road traffic noise there was significant heterogeneity between countries, but the estimated odds ratios using pooled analyses (adjusted for country) were similar to the computed estimate in the meta-analysis.

## **Discussion**

The HYENA study is the first to investigate the impact on blood pressure of exposure to noise from aircraft and road traffic near airports. There were significant exposure response relationships between exposure to night-time aircraft noise exposure, daily average road traffic noise and risk of hypertension.

There were no significant differences in effect between exposure to noise from aircraft and road traffic (Table 2), although the odds ratio for night-time aircraft noise was

somewhat higher than the odds ratio for road traffic noise. It should be noted that all airports but two (Bromma in Sweden and Berlin-Tegel) allow night-flights, although some restrictions are in place. However, given the national definitions of  $L_{\text{night}}$  (which are in accordance with the European Environmental Noise Directive), it is clear that there is substantial night-time exposure in all participating countries, particularly, in the "shoulder hours" in the late evening and early morning. The risk of hypertension related to night-time noise exposure tended to be more pronounced than for daytime aircraft noise exposure, although there is slight overlap of confidence intervals, and we cannot exclude some influence on odds ratios related to collinearity between the two aircraft noise variables (correlation coefficient=0.8).

The higher risk for night-time noise may be a consequence of less misclassification of exposure during the night (participants are more likely to be at home during the night than during day-time). The higher night-time risks may also be explained by acute physiological responses induced by night-time noise events that might affect restoration during sleep. Noise-induced instantaneous autonomic responses during sleep do not only occur in waking hours but also in sleeping subjects even when no (EEG recorded) awakening is present (Davies et al. 1993). They do not adapt on a long-term basis although a clear subjective habituation occurs after a few nights (Muzet 2002). Repeated arousals from sleep are associated with a sustained increase in daytime blood pressure (Morrell et al. 2000).

Smoking is a well established risk factor for cardiovascular disease, but its effect on blood pressure is less clear-cut (Green et al. 1986, Narkiewicz et al. 2005). Blood



pressure increases acutely after smoking, and we thus required that study participants refrained from smoking at least 30 minutes prior to blood pressure measurements. To assess whether smoking habits would confound the effects on blood pressure of noise, we initially included smoking in the regression model. However, smoking did not contribute significantly to the model and did not have any impact on the effect estimates of noise, and therefore smoking was not included in the final model.

Risk of hypertension may differ between ethnic groups, although risk patterns are not clear-cut (Sosin et al. 2004). Since ethnicity may also be related to living near airports, we aimed to include ethnicity as a confounding variable. However, ethnic groups differed much between countries and it was only feasible to combine the data into a crude dichotomous variable (white/non-white). The study population was predominantly white (94.4%) and inclusion of the dichotomous ethnicity variable in the analyses did not change the overall risk estimates.

The exposure-response relationship was more pronounced for men exposed to road traffic noise, supporting previous studies that have found excess risk of hypertension for men in relation to road traffic noise (Babisch et al. 2005, Belojevic and Saric-Tanaskovic 2002, Herbold et al. 1989) although the evidence is not fully consistent (Bluhm et al. 2007, Eiff and Neus 1980). There were no similar gender differences for aircraft noise.

In an attempt to explore if any gender differences were apparent in retired people (65 years or older), who may be more likely to spend most of their time at home, we analyzed this sub-sample of the study population (n= 1,076; 546 women and 530 men). We found

an excess risk in women for a 10dB increase in road traffic noise (OR=1.63, 95% CI: 1.21,2.20), but no significant excess risks for daytime (OR=.1.18, 95% CI: 0.82,1.71) or night-time (OR=0.91, 95% CI: 0.63,1.34) aircraft noise There were no significant risks in men for any of the noise exposure variables (road traffic noise: OR=1.03, 95% CI: 0.77,1.38 ; daytime aircraft noise; OR=0.96, 95% CI:0.65, 1.43; night-time aircraft noise: OR= 1.10, 95% CI: 0.73, 1.67). The confidence intervals are wide and include the point estimates derived for the total population, apart from women for road traffic noise. This apparent significant excess risk in women may be a result of less misclassification of exposure but could of course also be a chance finding.

Further research is needed to clarify the reason for the gender differences in risk related to (road traffic) noise exposure.

A potential weakness of our study is the low response rate in most of the participating countries. However, a descriptive analysis indicated only minor differences between participants and non-responders in distribution between aircraft noise exposure categories. However, for road traffic noise, contrary to what might have been expected, response rates were lower in the high exposure category; any potential bias related to this is difficult to assess, but is unlikely to be substantial. It should also be noted that the response rates for road traffic noise categories in particular are rather crude, since they are based on estimates from the selection procedure (Jarup et al. 2005). Furthermore, there were no apparent differences in the prevalence of hypertension between participants and non-responders. It is unlikely that health outcomes such as hypertension would give

rise to a selection bias, potentially resulting in falsely increased risks (Franssen et al. 2004).

Our results show differences in the prevalence of hypertension between participating countries, the UK having the lowest prevalence (48.8%) and Greece the highest (57.0). Our prevalence rates are in general higher than previously published data, although differences are difficult to interpret because of differences in population age structure (Kearney et al. 2005). However, relations between country prevalence are similar to the data published by Kearney et al. (2005), apart from Greece, which has a markedly lower prevalence in the previously published paper.

In conclusion, the HYENA study found statistically significant effects on blood pressure of night-time aircraft noise and average 24 hour road traffic noise exposure, the latter for men in particular. Hypertension is an important independent risk factor for myocardial infarction and stroke and the increased risk of hypertension in relation to aircraft and road traffic noise near airports demonstrated in our study may therefore contribute to the burden of cardiovascular disease. Our results indicate that preventive measures should be considered to reduce road traffic noise and night-time noise from aircraft.

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Table 1. Odds ratios (OR) of hypertension in relation to the main confounders.

Variable	OR	95% CI	P-value
Germany (vs UK)	1.34	1.07, 1.69	0.012
The Netherlands (vsUK)	1.30	1.03, 1.63	0.027
Sweden (vs UK)	1.44	1.15, 1.80	0.002
Greece (vs UK)	1.42	1.10, 1.83	0.007
Italy (vs UK)	1.22	0.95, 1.56	0.118
Age	1.07	1.06, 1.08	< 0.001
Gender (female vs male)	0.67	0.59, 0.76	< 0.001
Alcohol intake	1.01	1.00, 1.02	0.001
BMI	1.11	1.10, 1.13	<0.001
Exercise, 1-3 times a week vs less than once a week	0.96	0.81, 1.15	0.681
Exercise, more than 3 times a week vs less than once a week	0.82	0.71, 0.95	0.009
Education quartile 2 vs 1	1.01	0.83, 1.23	0.897
Education quartile 3 vs 1	0.81	0.68, 0.98	0.027
Education quartile 4 vs 1	0.83	0.69, 1.00	0.049

Country, age, gender, BMI, and alcohol intake, physical activity and exercise simultaneously included in the model. CI = confidence interval.

Table 2. Odds ratios (OR) of hypertension related to aircraft and road traffic noise using continuous variables, showing the risk per 10 dB increase in noise exposure.

Variable	OR	95% CI		p-value
$L_{Aeq16h}$ aircraft	0.928	0.829	1.038	0.190
$L_{night}$ aircraft	1.141	1.012	1.286	0.031
$L_{aeq,24h}$ road traffic	1.097	1.003	1.201	0.044

CI = confidence interval. All noise indicators included in the model. Adjusted for country, age, gender, BMI, alcohol intake, education and exercise.

Figure legends.

Figure 1. Odds ratios (OR) of hypertension in relation to aircraft noise (5dB categories).  $L_{\text{aeq},16\text{h}}$  (left) and  $L_{\text{night}}$  (right) separately included in the model. Adjusted for country, age, gender, BMI, alcohol intake, education and exercise. The error bars denote 95% confidence intervals for the categorical (5dB) analysis. The unbroken and broken curves show the OR and corresponding 95% confidence interval for the continuous analysis.

Figure 2. Odds ratios (OR) of hypertension in women (left) and men (right) in relation to road traffic noise ( $L_{\text{Aeq},24\text{h}}$ , 5dB categories) separately included in the model. Adjusted for country, age, BMI and alcohol intake, education and exercise. The error bars denote 95% confidence intervals for the categorical (5dB) analysis. The unbroken and broken curves show the OR and corresponding 95% confidence interval for the continuous analysis.

Figure 3. Forest plot showing country-specific odds ratios (OR) for hypertension per 10 dB increase in noise exposure, in relation to (A) night-time ( $L_{\text{night}}$ ) and (B) daytime ( $L_{\text{aeq},16\text{h}}$ ) aircraft noise and (C) 24 hour average road traffic noise ( $L_{\text{aeq},24\text{h}}$ ). The number of participants was 600 in the UK, 972 in Germany, 898 in the Netherlands, 1,003 in Sweden, 635 in Greece and 753 in Italy.

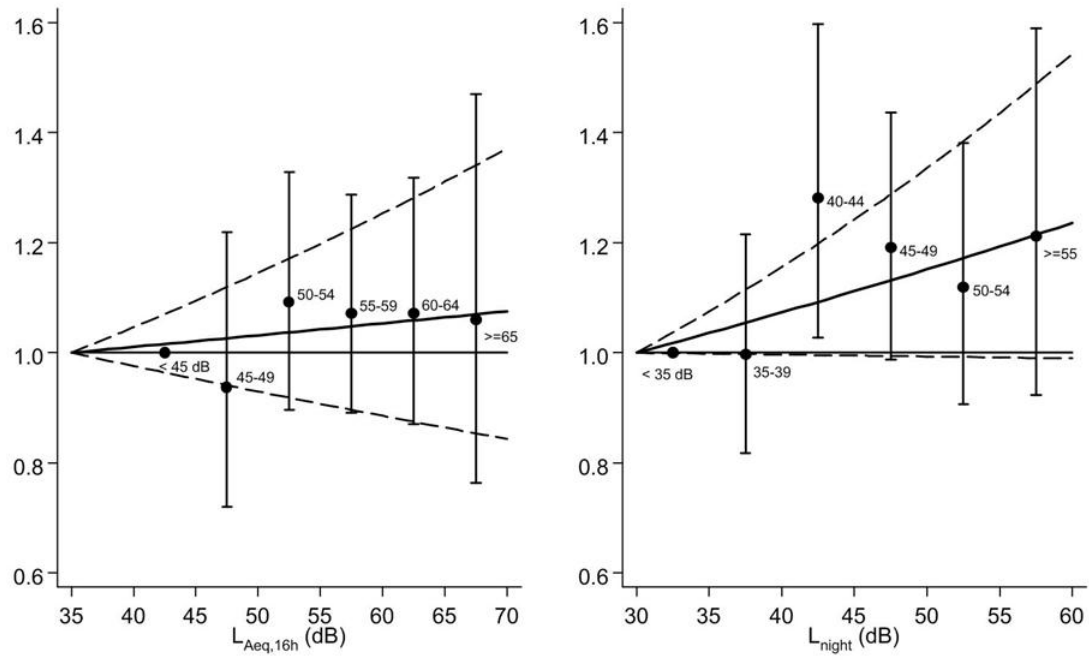


Figure 1

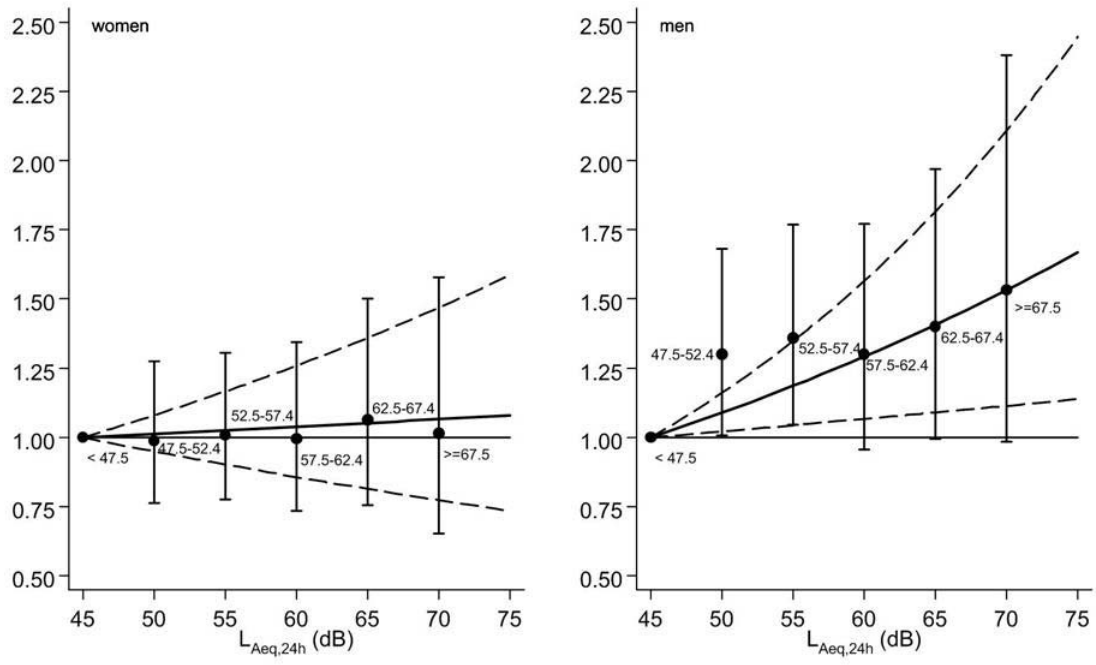


Figure 2

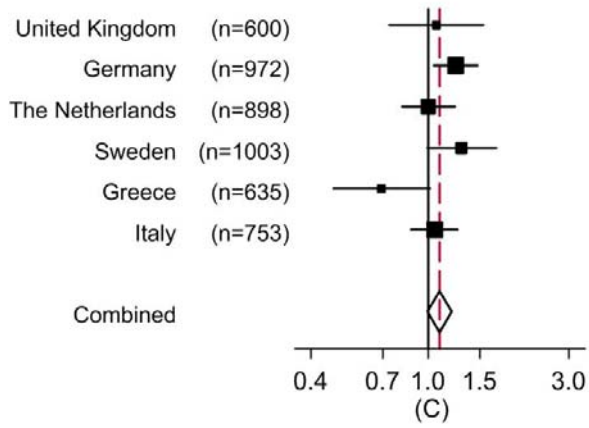
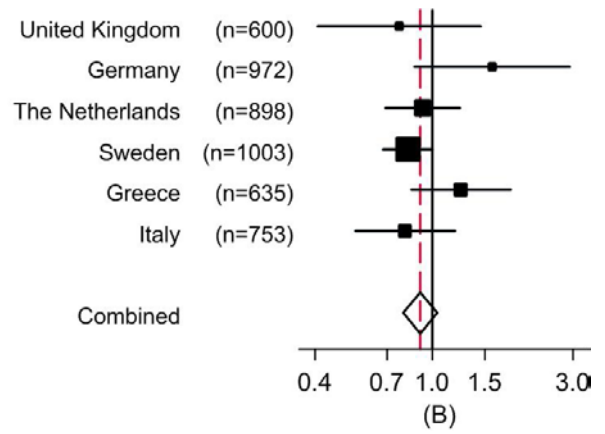
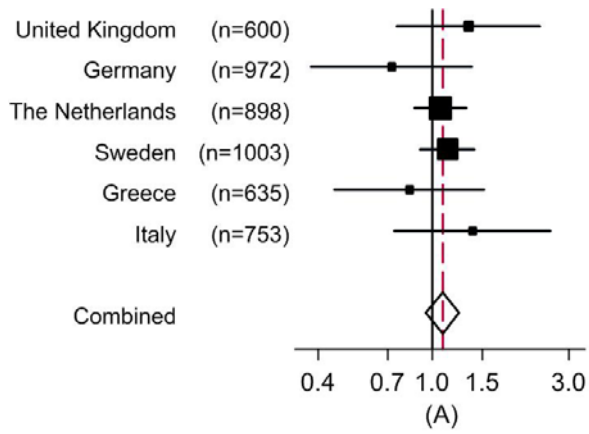


Figure 3