Original article

Scand J Work Environ Health 2006;32(5):392-401

doi:10.5271/sjweh.1035

Road traffic noise in southern Sweden and its relation to annoyance, disturbance of daily activities and health

by Björk J, Ardö J, Stroh E, Lövkvist H, Östergren P-O, Albin M

Affiliation: Competence Center for Clinical Research, Lund University Hospital, SE-221 85 Lund, Sweden. jonas.bjork@skane.se

Corrections

See 2007;33(1):80 for a correction.

The following article refers to this text: 2014;40(3):235-243

Key terms: annoyance; disturbance of daily activities; epidemiology; geographic information systems; health; noise; road traffic; Sweden; transportation

This article in PubMed: www.ncbi.nlm.nih.gov/pubmed/17091207

*O*riginal article

Scand J Work Environ Health 2006;32(5):392–401

Road traffic noise in southern Sweden and its relation to annoyance, disturbance of daily activities and health

by Jonas Björk, PhD,[1] Jonas Ardö, PhD,[2] Emilie Stroh, MSc,[2] Håkan Lövkvist, MSc,[1] Per-Olof Östergren, MD,[3] Maria Albin, MD,[4]

Björk J, Ardö J, Stroh E, Lövkvist H, Östergren P-O, Albin M. Road traffic noise in southern Sweden and its relation to annoyance, disturbance of daily activities, and health. *Scand J Work Environ Health* 2006;32(5):392–401.

Objectives This study investigated residential noise from road traffic and its relation to annoyance, disturbance of daily activities, and general health.

Methods A large public health survey in southern Sweden in 1999–2000 supplied data (N=13 557; 54% participation rate) on the demography, annoyance, and disturbance of daily activities, and on general health problems regarding concentration, sleep, stress, and treatment for hypertension. Residential road noise exposure was assessed with a geographic information system. Associations with 24-hour equivalent (average) and maximum road noise level were investigated for all participants and for selected subgroups using the Cochran-Armitage trend test and Cox regression analysis.

Results Annoyance from road traffic noise and the disturbance of daily activities increased markedly with road noise exposure. More than 25% reported at least occasional disturbance from traffic noise during relaxation and sleep in the highest exposure category for each noise measure. No overall pattern between road noise exposure and general health problems emerged. Among the participants that reported annoyance from road traffic noise (N=623), the average road noise level was associated with concentration problems (P for trend = 0.03) and with treatment for hypertension (P for trend = 0.02). Positive associations between average road noise exposure and health problems were found among females (hypertension), persons born outside Sweden (sleep), the unemployed (stress), and participants that reported financial problems (concentration problems).

Conclusions Exposure to road traffic noise at high levels was common and produced frequent disturbances of daily activities. Negative health effects from road traffic noise were observed in important subgroups. The findings are of concern for southern Sweden, as well as for other regions with similar or higher traffic intensity.

Key terms epidemiology; geographic information systems; noise, transportation.

With the exception of direct damage to the hearing organ caused by sound exposure, the individual perception of sound as negative (ie, as noise) is likely to be an important determinant of its health effects (1, 2). Annoyance from noise exposure may stem from, or may generate, disturbance in daily life such as sleep, relaxation, concentration, conversation, listening to the radio, and watching television. The prevalence of annoyance increases with increasing equivalent sound levels (3), but is determined also by fear in association with the noise source and individual noise sensitivity (4). General demographic variables are less strong determinants of annoyance (5). It has been suggested that increased vulnerability to stress-inducing factors could trigger annoyance from noise (3), and studies of critical subgroups and the role of annoyance as a mediator of health effects have been encouraged (6). Nonauditory physical health effects that are biologically plausible in relation to noise exposure and annoyance from noise exposure include changes in blood pressure, heart rate,

1 Competence Center for Clinical Research, Lund University Hospital, Lund, Sweden.
2 Department of Physical Geography and Ecosystems Analysis, Lund University, Lund, Sweden.
3 Department of Health Sciences, Division of Social Medicine and Global Health, Malmö University Hospital, Malmö, Sweden.
4 Department of Occupational and Environmental Medicine, Lund University Hospital, Lund, Sweden.

Reprint requests to: J Björk, Competence Center for Clinical Research, Lund University Hospital, SE-221 85 Lund, Sweden. [E-mail: jonas.bjork@skane.se]

and levels of stress hormones (7), which may increase the risk of hypertension and ischemic heart disease (1, 2, 8, 9).

Residential noise is experienced in closed rooms of dwellings as a result of noise sources unrelated to the dwelling, and it is measured outside at the facade (10). Approximately 30% of the population in the European Union is exposed to a day–night equivalent level (L_{dn}, appendix 1) of traffic noise exceeding 55 dB(A) at a residence; therefore transport (by road, rail, or air) is the most important source of community noise in Europe (11). Very high 24-hour equivalent levels ($L_{Aeq,24}$, appendix 1) greater than 65 dB(A) seem to have stabilized in some countries, while exposure in the range 55–65 dB(A) has significantly increased as a result of the fast growing volume of road traffic (12). Noise exposure has been forecast to worsen along ring roads and motorways, and at nearby regional airports, because of the growth in transportation, especially freight and air traffic (13). In Sweden, 16% of the population was estimated to be exposed to equivalent noise levels exceeding 55 dB(A) from road traffic in the year 2000, with no certain overall time-trend since 1995 (14). Frequent annoyance (at least once a week) due to noise from road traffic was reported by 9% in a Swedish survey in 1999 (15), and by 18% in our preliminary calculations based on survey data from the region of Skåne (the Scania region) in southern Sweden in 2004 (16).

The aim of the present study, which used data from a large public health survey conducted in southern Sweden in 1999–2000, was to investigate residential noise originating from road traffic and its relation to annoyance, the disturbance of daily activities, and general health. It was of special interest to investigate health effects among people annoyed by road traffic noise and in subgroups that are possibly more vulnerable.

Study population and methods

Public health survey

In order to investigate the relation between road traffic noise and possible health effects, we used data from a large public health survey distributed as a mailed questionnaire (17). The study population for the survey was defined as all persons at least 18 and at most 80 years of age and living in any of 33 municipalities in the Scania region in southern Sweden in November 1999. After stratifying the study population into 60 different geographic areas, we randomly selected samples of approximately equal size for each stratum from the population register. The total sample comprised 24 945 persons, and the questionnaires were mailed between November 1999 and April 2000. Three mailed reminders and one reminder by telephone were used to increase the participation rate. In the end, answers were obtained from 13 604 (54.5%) of the 24 945 persons selected for the health survey. The reasons for nonparticipation were no reply (63.0%), refusal (25.2%), unable to answer due to illness, traveling or other reasons (6.9%), invalid address in register (3.9%), and answer from wrong person (1.0%). The participation rates were generally higher for the women than for the men and generally increased with age. A detailed analysis of the nonparticipants showed that persons with low education and persons born outside the Nordic countries were underrepresented among the participants (18). For the 13 604 participants, it was possible to obtain residential geocodes for 13 557 persons.

In the mailed questionnaire, detailed questions were asked regarding self-reported health, long-term diseases and sick-leaves, treatment with drugs, health-care usage, annoyance from environmental factors [electrical equipment and smells (19)], social network, occupation and work environment, smoking habits, alcohol consumption, physical exercise, financial situation, education, civil status, country of origin, and residential environment. The health sections of the questionnaire included questions about ability to concentrate during the last weeks [General Health Questionnaire—12 (20)], sleeping disturbance during the last 2 weeks, insufficient sleep in general, stress, and treatment for hypertension during the past 12 months. These general health questions were asked without traffic noise or any other exposure being referred to. In the section about residential environment, specific noise-related questions were asked about traffic noise disturbances of daily activities, together with three general questions about annoyance from roads, trains, and aircraft (see appendix 2).

Assessment of road traffic noise

No measurements of sound levels were conducted. Instead, we used a geographic information system (GIS) to assess the outdoor noise exposure from traffic noise. Geocoded residential addresses at the end of 1999 for the participants in the public health survey and road traffic data were used. No data on train traffic or aircraft were available. Road traffic data included 21 397 road segments (17 339 administrated by the Swedish Road Administration, and 4 058 by local municipalities). The number of vehicles was available for 82% of the road segments. Speed limits were available for >95% of the segments. Some of the traffic data had not been fully updated, but 93% were from 1985 or later, and 71% were from 1995 or later. For road segments without traffic data, mean values were assigned to each segment on the basis of existing data for the included road types (21).

Using the road traffic data, we used a simplified version of the Nordic prediction method for road traffic noise [see the reports by Bendtsen (22) and Jonasson et al (23) for a complete description] to estimate noise exposure for the residential locations of the study participants. In short, the Nordic prediction method first calculates the unattenuated noise level 10 meters from the road center using the number of light and heavy vehicles and the speed limit of each road segment. Corrections are then calculated for (i) the distance between the source (the road) and receptor, for which the noise levels decrease by 3 dB with a doubling of the distance, (ii) attenuation due to ground surface type and noise barriers [the attenuation of noise depends on surface type with less attenuation for hard surfaces (asphalt, water, concrete) and more attenuation for soft surfaces (vegetation, grass, etc)], and (iii) additional corrections for special cases (including very steep topography, reflection from buildings, etc).

In this study, we had to simplify the Nordic prediction method by using corrections for distance and surface type only. We were not able to correct for noise barriers and the additional special cases already mentioned, as no such data were available.

We assumed flat ground in all cases and soft surfaces between the residence and the road for the participants living in the countryside (N=2199), while a hard surface was assumed for the participants living in more densely populated areas (N=11 358). We had no data indicating the floor of the apartment building on which

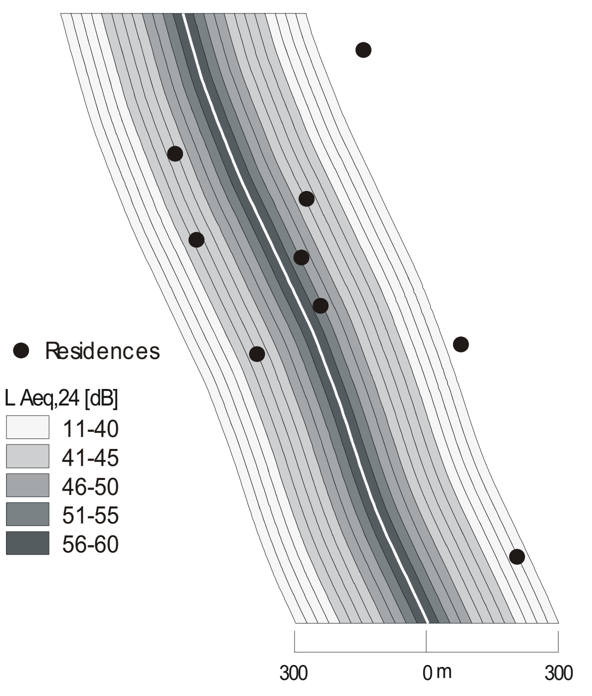

Figure 1. An example of an estimated A-weighted equivalent (average) noise level during a full day ($L_{Aeq,24}$) outside the residences in each 25-meter zone next to an arbitrary road segment.

the residences were located, and we therefore estimated the noise level on the ground floor for all of the residences. We estimated the A-weighted equivalent noise level over a full day (24 hours, $L_{Aeq,24}$), and the A-weighted maximum noise level with fast time weighting (L_{Afmax}) (appendix 1). Estimated noise levels during the day and night were too strongly correlated with the noise level during a full day to be used for separate analyses. Using the number of vehicles (light and heavy) and the speed limit for each road segment, we calculated $L_{Aeq,24}$ and L_{Afmax} for each 25-meter zone up to 300 meters from the center of the road. Figure 1 illustrates the outdoor noise exposure for the residences in each 25-meter zone next to an arbitrary road segment.

As people may appear in noise zones for more than one road segment, the maximum values for $L_{Aeq,24}$ and L_{Afmax} across all of the road segments near the residence were extracted for each person and used for further analyses. Road noise exposure was categorized according to the equivalent (average) noise level over a full day [$L_{Aeq,24}$, low if <50 dB(A), medium if 50–54 dB(A), and high if ≥55 dB(A)] and according to the maximum noise level [L_{Afmax}, low if <60 dB(A), medium if 60–69 dB(A), and high if ≥70 dB(A)]. Fifty percent of all of the geocoded participants were assigned the same exposure category (low, medium, high) for both the average and maximum noise level.

Statistical analysis

For noise from each traffic source, the participants reporting fairly much or much annoyance were classified as "annoyed", whereas those reporting no or not much annoyance were classified as "not annoyed" (appendix 2). Associations between the general background characteristics of the participants and exposure category (low, medium, high) and the prevalence of annoyance (fairly much or much) from road traffic noise were investigated using the chi-square test. If data suggested monotonically increasing or decreasing trends in the prevalence of disturbance (occasional or frequent), annoyance, and self-reported health problems in relation to exposure category, we tested these trends with the Cochran-Armitage trend test (24), using StatXact-6 (Cytel Software Corporation, Cambridge, MA, USA). Trends in health problems were investigated overall, as well as separately, among the participants who were annoyed by road traffic noise. In addition, we also analyzed self-reported health problems in relation to exposure category in the following subgroups, which we hypothesized as being possibly more vulnerable due to exposure to social stressors and for which we observed higher prevalences of annoyance: women, persons born outside Sweden, those unemployed, and persons that reported financial problems. Observed trends for health problems were investigated further with Cox regression with a constant risk period (equal to one) (25), using SPSS 12.0.1 for Windows (SPSS Inc, Chicago, IL, USA). In the Cox regression analyses, we adjusted for gender, age in three broad groups (<45 years, 45–64 years, and ≥65 years), and, when treatment for hypertension was investigated, body mass index in five groups (missing, <20, 20–24, 25–29, and ≥30 kg/m^2). We considered P-values below 0.05 and 95% confidence intervals (95% CI) for prevalence ratios that excluded unity as significant.

Population prevalences were estimated in weighted statistical analyses, which accounted for the stratified sampling scheme with respect to geographic area and the selective participation with respect to gender and age.

Results

Associations with exposure and annoyance

We estimated that 29% (95% CI 28–30) of the study population, in the Scania region in southern Sweden, had a high average exposure [ie, $L_{Aeq,24}$ ≥55 dB(A)] to road traffic noise and that 37% (95% CI 36–37) had a high maximum exposure [ie, L_{Afmax} ≥70 dB(A)]. Country of origin; civil, smoking, and employment status; type of residence; and financial problems were all markedly associated with both average and maximum road noise exposure (P≤0.002 for all of these associations). In particular, living in apartment buildings was much more common among people with high average or maximum exposure to road traffic noise than among others (table 1).

Table 1. Characteristics of the 13 557 participants in the public health survey in the Scania region in southern Sweden in 1999–2000 in relation to exposure to and annoyance from road traffic. The exposure was categorized according to an equivalent (average) noise level over a full day ($L_{Aeq,24}$) of at least 55 dB(A) and according to a maximum noise level (L_{Afmax}) of at least 70 dB(A). The participants who reported fairly much or much annoyance from road traffic noise were categorized as "annoyed". All of the characteristics are given as the percentage if not otherwise stated.

Variable	Number of responses	All		Average ≥55 dB(A) (N=3489)		Maximum ≥70 dB(A) (N=4509)		Annoyance from road traffic (N=623)	
		Median	2.5th–95th percentiles	Median	2.5th–95th percentiles	Median	2.5th–95th percentiles	Median	2.5th–95th percentiles
Age (years)	13 557	49	19–78	48	19–78	49	20–78	48	20–77
Females	13 557	54.4	·	54.9	·	54.9	·	58.4	·
Born in Sweden	13 377	89.3	·	85.1	·	86.7	·	83.5	·
Married or cohabiting	13 289	70.4	·	62.2	·	64.9	·	65.3	·
Body mass index (kg/m^2)	13 080	25	19–34	24	19–34	24.5	19–34	25	18–34
Physical exercise	12 971								
Mainly sedentary		15.1	·	15.7	·	16.1	·	19.7	·
Light		63.2	·	61.5	·	62.2	·	59.9	·
Regular or hard		21.8	·	22.8	·	21.7	·	20.4	·
Smoking status	13 314								
Never		50.7	·	49.4	·	49.5	·	50.8	·
Former		26.4	·	25.4	·	25.4	·	25.3	·
Current		22.9	·	25.2	·	25.2	·	23.8	·
Educational level	12 882								
≤9 years at school		33.0	·	31.7	·	33.5	·	33.2	·
10–12 years at school		30.7	·	30.4	·	29.8	·	29.9	·
Vocational training		10.2	·	10.2	·	10.6	·	9.9	·
University		26.1	·	27.7	·	26.2	·	27.1	·
Employment status	12 471								
Employed		57.5	·	51.8	·	54.5	·	46.5	·
Retired or on sick-leave		25.0	·	27.2	·	27.3	·	30.8	·
Student		8.8	·	11.4	·	10.0	·	10.9	·
Unemployed		5.1	·	5.9	·	5.0	·	6.2	·
Works at home		3.6	·	3.6	·	3.2	·	5.5	·
Type of residence	13 044								
Private house		51.8	·	32.1	·	41.3	·	44.5	·
Apartment block		29.1	·	52.2	·	43.3	·	37.1	·
Terrace house		13.6	·	10.3	·	10.2	·	9.3	·
Other		5.5	·	5.4	·	5.3	·	9.0	·
Problems with paying bills	13 137								
Never		71.2	·	67.9	·	69.5	·	61.1	·
Only very occasionally		19.0	·	20.4	·	19.6	·	22.3	·
At least every second month		9.8	·	11.6	·	10.9	·	16.7	·

The proportions of people born in Sweden, married or cohabiting, and employed were somewhat lower, whereas the proportion of current smokers and the proportion of people that reported financial problems were somewhat higher among those with high road noise exposure. These differences were generally more marked when exposure was grouped according to the average noise level than according to the maximum noise level. Exposure did not differ noticeably with respect to the age, gender, body mass index, physical exercise, or educational level of the participants.

Fairly much or much annoyance from road traffic noise was reported by 4.7% (95% CI 4.4–5.1, weighted analysis yielding an identical population estimate). Gender, country of origin, civil status, physical exercise, employment status, type of residence, and financial problems were all associated with the prevalence of annoyance (fairly much or much) from road traffic noise (P≤0.005 for all of these associations except gender, for which P=0.036). In particular, the proportion of employed persons was much lower among the annoyed than among others (table 1).

Annoyance from road traffic noise increased markedly with road noise exposure (table 2) (P<0.001 for all of the associations). No marked associations between exposure to road traffic noise and fairly much or much annoyance from aircraft or train noise were observed.

Disturbance of daily activities and self-reported health problems

Disturbance of daily activities (sometimes or frequent) increased with both average and maximum road noise exposure (table 3) (P<0.001 for all associations). More than 25% reported at least occasional disturbance from traffic noise during relaxation and sleep in the highest exposure category for each noise measure.

Among the participants, no consistent pattern between road noise exposure and health problems emerged (table 4). However, extensive sleep disturbance during the last 2 weeks was more common among the participants with medium or high average road noise exposure (P for trend = 0.01), the same trend was observed in the multivariable analysis using Cox regression. The prevalence ratio for extensive sleeping disturbances during the last 2 weeks, in contrast to the average exposure, ≥55 dB(A) with exposure below 50 dB(A), was 1.2 when unadjusted or when adjusted for gender and age (95% CI 1.1–1.4).

Self-reported health problems among the annoyed participants

The participants who were fairly much or much annoyed from road traffic noise (N=623) (table 4) experienced more health problems than the other participants. Among these annoyed participants, an association was observed between average road noise exposure and concentration problems during the last few weeks (P for trend = 0.03). Concentration problems were also more common among the annoyed participants with moderate or high maximum road noise exposure. The unadjusted prevalence ratio for concentration problems during the last few weeks among the annoyed persons, in contrast to average exposure, ≥55 db(A) with exposure below 50 dB(A), was 1.5 (95% CI 0.95–2.5), and the prevalence ratio adjusted for gender and age was 1.7 (95% CI 1.0–2.7).

Among the participants who were fairly much or much annoyed from road traffic noise, an association between the average noise level from road traffic and treatment for hypertension was also observed (P for trend = 0.02) (table 4). The unadjusted prevalence ratio for treatment for hypertension among the annoyed, when

Table 2. Self-reported annoyance (fairly much and much) from traffic noise at the residence in relation to road noise exposure [a] among the 13 557 participants in the public health survey in the Scania region in southern Sweden in 1999–2000. Road noise exposure was categorized according to the equivalent (average) noise level over a full day [$L_{Aeq,24}$: low if <50 db(A) (N=6564), medium if 50–54 db(A) (N=3504), and high if ≥55 db(A) (N=3489)] and according to the maximum noise level [L_{Afmax}: low if <60 db(A) (N=3528), medium if 60–69 db(A) (N=5520), and high if ≥70 db(A) (N=4509)].

Source of annoyance	Total number of responses	Annoyance (%) among all		Noise measure	Annoyance (%) in relation to exposure category					
					Low exposure		Medium exposure		High exposure	
		Fairly much	Much		Fairly much	Much	Fairly much	Much	Fairly much	Much
Road traffic noise	13 168	3.7	1.0	Average	1.6	0.4	4.0	1.0	7.4	2.1
				Maximum	1.4	0.5	3.1	0.7	6.4	1.7
Aircraft noise	12 989	1.3	0.3	Average	1.4	0.4	1.5	0.3	0.9	0.3
				Maximum	1.5	0.4	1.2	0.3	1.2	0.3
Train noise	12 994	1.5	0.5	Average	1.3	0.6	1.9	0.4	1.5	0.5
				Maximum	1.3	0.5	1.5	0.6	1.7	0.4

[a] The P-values for trend were below 0.001 for the prevalence of fairly much or much annoyance from road traffic in relation to both the average and maximum road noise level. No positive associations were found between exposure to road traffic noise and annoyance from aircraft or train noise.

Table 3. Self-reported disturbance of daily activities (sometimes or frequently) from traffic noise at the residence in relation to road noise exposure [a] among the 13 557 participants of the public health survey in the Scania region in southern Sweden in 1999–2000. Road noise exposure was categorized according to the equivalent (average) noise level over a full day [$L_{Aeq,24}$: low if <50 db(A) (N=6564), medium if 50–54 db(A) (N=3504), and high if ≥55 db(A) (N=3489)] and according to the maximum noise level [L_{Afmax}: low if <60 db(A) (N=3528), medium if 60–69 db(A) (N=5520), and high if ≥70 db(A) (N=4509)]. (Frequently = every week)

Daily activity	Total number of responses	Disturbance among all		Noise measure	Disturbance (%) in relation to exposure category					
					Low exposure		Medium exposure		High exposure	
		Sometimes	Frequently		Sometimes	Frequently	Sometimes	Frequently	Sometimes	Frequently
Relaxation	12 947	18.4	2.2	Average	12.1	1.1	20.4	2.3	28.1	3.9
				Maximum	10.8	0.9	17.0	2.0	26.0	3.3
Sleep	12 948	18.9	1.7	Average	13.6	1.3	21.3	1.7	26.6	2.6
				Maximum	11.4	0.9	18.4	1.7	25.5	2.4
Falling asleep	13 007	16.7	2.0	Average	11.8	1.6	18.6	1.8	23.9	2.9
				Maximum	9.9	1.1	16.1	2.0	22.7	2.6
Hearing radio or television	13 114	12.1	2.0	Average	7.2	1.1	13.6	2.2	19.8	3.6
				Maximum	5.9	1.0	10.2	1.9	19.3	3.0
Conversation	12 974	5.2	0.7	Average	3.5	0.4	5.4	1.0	8.2	1.1
				Maximum	3.0	0.5	4.4	0.6	7.9	1.0
Telephone conversation	13 016	4.4	0.7	Average	2.9	0.4	4.7	0.9	6.8	0.9
				Maximum	2.8	0.6	3.8	0.5	6.3	1.0

[a] The P-values for trend were all below 0.01 for the prevalences of disturbance of daily activities (sometimes or frequently) in relation to both the average and maximum road noise exposure.

Table 4. Self-reported general health problems among the 13 557 participants of the public health survey in the Scania region in southern Sweden in 1999–2000 in relation to annoyance and exposure from road traffic. Road noise exposure was categorized according to the equivalent (average) noise level over a full day [$L_{Aeq,24}$: low if <50 db(A) (N=6564), medium if 50–54 db(A) (N=3504), and high if ≥55 db(A) (N=3489)] and according to the maximum noise level [L_{Afmax}: low if <60 db(A) (N=3528), medium if 60–69 db(A) (N=5520), and high if ≥70 db(A) (N=4509)].

	Average noise level				Maximum noise level			
	Low	Medium	High	P-value [a]	Low	Medium	High	P-value [a]
All participants (N)	6564	3504	3489		3528	5520	4509	
Concentration problems in the last few weeks (%)	13.3	13.3	14.7	0.08	13.2	13.7	14.0	0.30
Extensive sleeping disturbance in last two weeks (%)	7.2	8.5	8.6	0.01	7.1	8.3	8.1	·
Insufficient sleep generally (%)	8.8	9.4	9.4	0.27	8.8	9.1	9.5	0.26
Frequently under stress (%)	18.9	18.8	19.3	>0.30	19.3	19.2	18.5	·
Treatment for hypertension in last 12 months (%)	10.0	10.1	10.5	>0.30	9.8	9.8	10.8	0.12
Fairly much or much annoyance from road traffic noise (N)	129	171	323		66	205	352	
Concentration problems in the last few weeks (%)	16.3	19.9	25.1	0.03	13.8	25.0	21.4	·
Extensive sleeping disturbance in last two weeks (%)	18.6	15.2	15.1	·	12.3	17.2	15.8	·
Insufficient sleep generally (%)	18.8	14.7	17.4	·	12.3	17.6	17.5	·
Frequently under stress (%)	27.3	27.1	28.2	·	23.1	36.8	23.3	·
Treatment for hypertension in last 12 months (%)	7.9	8.3	14.7	0.02	7.8	11.4	12.4	>0.30

[a] Monotonically increasing or decreasing trends in the prevalence of health problems in relation to the exposure category were tested with the Cochran-Armitage trend test.

those exposed to noise levels ≥55 dB(A) were contrasted to those with exposure below 55 dB(A), was 1.8 (95% CI 1.1–3.0), and the prevalence ratio adjusted for gender, age, and body mass index was 1.7 (95% CI 1.0–2.7). The association between an average noise level of road traffic [<50 dB(A), 50–54 dB(A), ≥55 dB(A)] and treatment for hypertension was present among the annoyed male participants (3.8%, 9.4%, 13.8%, respectively) (N=255), but it was not entirely consistent among the annoyed female participants (11.0%, 7.6%, 15.5%, respectively) (N=359).

Self-reported health problems in possibly more vulnerable subgroups

When the analyses were restricted to women, the participants born outside Sweden, the unemployed, and those who reported financial problems, no apparent associations with maximum road noise exposure were observed. However, the following positive associations between average road noise exposure [<50 dB(A), 50–54 dB(A), ≥55 dB(A)] and the prevalence of health problems were found: treatment for hypertension among women (9.3%, 9.8%, and 11.1% treated, respectively, P for trend = 0.04), insufficient sleep among the participants born outside Sweden (10.4%, 9.9%, and 14.6%, respectively, P for trend = 0.04), frequent stress among the unemployed (16.1%, 20.6%, 23.4%, respectively, P for trend = 0.04), and concentration problems during the last few weeks among the participants that had had problems paying bills at least every second month (25.0%, 27.9%, and 32.1%, respectively) (P for trend = 0.02). The multivariate analyses did not alter these trends (results not shown).

Discussion

Our estimated prevalence (29%) of average exposure to road traffic noise of at least 55 dB(A) ($L_{Aeq,24}$) is close to the overall estimates for the European Union and much higher than previous national estimates for Sweden (16%). An advantage with our model, as compared with the use of national estimates, is that we could include data on vehicles for road segments belonging to the local municipalities, which is important especially for those who live in an urban environment. Parts of our data on traffic intensity were not up to date, however, and therefore may have produced some misclassification of exposure. We were able to differentiate between urban (hard surface) and rural (soft surface) areas in the model. This statement is of course an oversimplification since not all grounds in cities are hard, the implication being that we may, to some extent, have overestimated urban exposure. Lack of data on noise barriers and floor for residences in apartment buildings may also have produced overestimations of noise levels. Since a large proportion of the participants (1142 of 13 557, 8.4%) was assessed by our model as being exposed to 55–56 dB(A), a systematic misclassification of, say, +2 dB(A) would inflate the estimated proportion exposed to ≥55 dB(A) substantially. However, we observed clear associations between modeled exposure and reported annoyance from road traffic noise, the indication being that we managed to differentiate fairly well between different exposure levels. Furthermore, the high prevalence of disturbance of daily activities that we observed, and the high prevalence of frequent annoyance due to noise from road traffic in preliminary results from a more recent survey in 2004 (16), suggests that the levels of road noise exposure are indeed of concern in the Scania region in southern Sweden.

High exposure to road noise was more common among those not born in Sweden, living single, and not employed. Lack of equity with regard to exposure to adverse environmental factors, including traffic noise, has previously been reported from the United States (26), Germany (27), the Netherlands (28), and Birmingham in the United Kingdom (29). To the best of our knowledge, this is the first such report regarding road traffic noise from Scandinavia.

Fairly much, or much, annoyance due to road traffic noise was reported by 4.7% of all the participants, by 9.5% of those exposed to ≥55 dB(A) and by 8.1% of those exposed to maximal levels of ≥70 dB(A). It is likely that the threshold for positive reporting was rather high in the general survey question about road traffic annoyance, since disturbed sleep or relaxation (sometimes or frequently) was reported by much higher proportions (19–32%) in the highest exposure categories. The exact phrasing of the question can be expected to be critical since higher prevalences of annoyance have been observed in studies in which more specific questions about the frequency of the annoyance were asked. The preliminary estimate based on survey data from Scania in 2004 shows that about 18% of the population is annoyed at least once a week by road traffic noise, and a recent Swedish report found that more than 15% of the participants exposed to >55 dB(A) were annoyed frequently (every week) (3, 16). Traffic in general has been reported as the most important source of annoyance but noise in Sweden, followed by noise from neighbors (15). A spillover from being annoyed by noise from one means of transportation to another may therefore be a concern. However, we found that people with high exposure to road noise did not report more annoyance from noise from trains or aircraft than those with low exposure to road noise. The observed trends between annoyance, disturbance of daily activities, and exposure level in our study were striking and consistent for average noise levels, as well as for maximum noise levels, being generally at least doubled from the lowest to the highest exposure categories. Given that 29% of the population was estimated to be in the highest exposure category, this is a finding of concern. Disturbances of daily activities were somewhat more frequent for high average noise exposure than for high maximum noise exposure.

We observed no associations between the maximum level of road traffic noise and self-reported general health problems. For the average noise level, we found a weak overall association with extensive sleeping disturbances during the last week, whereas an association with insufficient sleep was generally not apparent. Consistent data from other studies indicate that exposure to occupational noise and noise from aircraft increases the risk of hypertension, but the findings are less consistent with regard to road traffic (2). We found an association between average road noise level and treatment for hypertension among the women and also among the men who reported fairly much or much annoyance from road traffic.

It is well known that sensitivity to noise varies widely between persons. Within the subgroup that reported annoyance from road traffic noise, we found associations with concentration problems during the last few weeks, as well as with treatment for hypertension. Noise-sensitive people have, in several studies, been shown to have poorer performance than nonsensitive people under noisy conditions (30), while no such difference was evident under silent conditions (31). The support for a higher risk of hypertension among people who are noise sensitive is weaker. However, an experimental study has shown a disruption of the cortisol pattern from exposure to low-frequency noise that was evident only for people who rated themselves as noise sensitive (32).

Positive findings for subgroups should be interpreted with care unless supported by other data. Some of the associations we observed for the self-reported general health problems in the 26 subgroup analyses (5 groupings of the participants × 5 different outcomes + annoyed men versus treatment for hypertension), generally with lower socioeconomic status, may have been due to chance. They may, however, also represent findings in especially vulnerable groups exposed to multiple social stressors. Socioeconomic status may not only be inversely associated with exposure, but also with vulnerability. Among children in rural areas in the United States, adverse environmental exposure was not only associated with low income, but cumulative exposure was also associated with effects, as monitored by increased levels of stress hormones, only among the low-income children and not in the middle-income sample (26). Among the unemployed in our present study, feeling frequently under stress was more common among those with a high average exposure to road noise, as was concentration problems among the people who reported financial problems. In addition, an association between insufficient sleep in general and average road noise level was suggested for those born outside Sweden.

The participation rate was low (54%) and differed with age, gender, education, and country of origin (18). Among these factors, country of origin varied with exposure among the participants. Thus some association between exposure and participation was probably present and may have produced bias if the participation was associated with any of the health parameters under investigation as well. The validity of the questionnaire should also be considered. A large study has shown high agreement between self-reported hypertension and medical records (kappa = 0.80, sensitivity = 82%, specificity = 92%, N = 2037) (33). Similar but smaller studies of self-reported hypertension have reported moderate-to-high agreement with medical records (34, 35). Misclassification of treatment for hypertension, if independent of noise exposure level, would tend to yield bias towards the null (36). The question about concentration ability during the last few weeks, in relation to their usual ability, was taken from a well-established instrument, the General Health Questionnaire—12 (20). The questions about sleep and stress were specific for the present and similar surveys in Scania. The question about problems with paying bills, used to identify persons with financial problems in the subgroup analyses, has been linked to poor self-rated health (37).

In conclusion, exposure to road traffic noise at high levels was common in the study population, and it produced frequent annoyance and disturbances of daily activities. Associations between road traffic noise and negative health effects were observed among the annoyed participants and in other important subgroups.

Acknowledgments

We are grateful to Susanna Gustafsson, GIS Centre, Lund University, for providing the road traffic data and to Åke Boalt at the county council of the Scania region for his assistance with the geocoding.

The project was supported by grants from the Swedish Environmental Protection Agency (Naturvårdsverket).

References

1. Passchier-Vermeer W, Passchier WF. Noise exposure and public health. Environ Health Perspect. 2000;108 suppl 1:123–31.
2. van Kempen EE, Kruize H, Boshuizen HC, Ameling CB, Staatsen BA, de Hollander AE. The association between noise exposure and blood pressure and ischemic heart disease: a meta-analysis. Environ Health Perspect. 2002;110:307–17.
3. Bluhm G, Nordling E, Berglind N. Road traffic noise and annoyance—an increasing environmental health problem. Noise Health. 2004;6:43–9.
4. Reijneveld SA. The impact of the Amsterdam aircraft disaster on reported annoyance by aircraft noise and on psychiatric disorders. Int J Epidemiol. 1994;23:333–40.
5. Miedema H, Vos J. Demographic and attitudinal factors that modify annoyance from transportation noise. J Acoust Soc Am. 1999;105:3336–44.
6. Babisch W. The noise/stress concept, risk assessment and research needs. Noise Health. 2002;4:1–11.
7. Babisch W. Noise and health. Environ Health Perspect. 2005;113:A14–5.
8. Rosenlund M, Berglind N, Pershagen G, Jarup L, Bluhm G. Increased prevalence of hypertension in a population exposed to aircraft noise. Occup Environ Med. 2001;58:769–73.
9. Babisch W, Beule B, Schust M, Kersten N, Ising H. Traffic noise and risk of myocardial infarction. Epidemiology. 2005;16:33–40.

10. World Health Organization, Regional Office of Europe. Concern for Europe's tomorrow: health and the environment in the WHO European Region. Stuttgart (Germany): Wissenschafliche Verlagsgesellschaft; 1995.
11. Transport-related health effects with a particular focus on children. Geneva: World Health Organization, Regional Office for Europe; 2004.
12. European Environmental Agency. Europe's environment—The Dobris assessment, chapter 16.2. Copenhagen (Denmark): European Environmental Agency; 1995.
13. European Environmental AgencyEnvironment in the European Union at the turn of the century: environmental report no 2. Copenhagen (Denmark): European Environmental Agency; 1999.
14. Odebrant T. Uppskattning av antalet exponerade för vägtrafiksbuller överstigande 55 dB(A) [Estimation of the number exposed to noise levels from road traffic exceeding 55 dB(A)]. Gothenburg (Sweden): Naturvårdsverket, Ingemansson Technology AB, 2002. Report S-13570-A.
15. Socialstyrelsen. Miljöhälsorapport 2001 (Environmental health 2001). Stockholm (Sweden): Socialstyrelsen, 2001.
16. Rosvall M, Ali Khan F, Nilsson M, Östergren P-O. Hälsoförhållanden i Skåne: folkhälsoenkät Skåne 2004 (Public health in the Scania region: health survey 2004). Malmö (Sweden): Region Skåne; 2005.
17. Region Skåne, Kommunförbundet Skåne, Skåne Läns Allmänna Försäkringskassa. Hälsoförhållanden i Skåne (Public health in the Scania region). Malmö (Sweden): Region Skåne, Kommunförbundet Skåne, Skåne Läns Allmänna Försäkringskassa, 2000.
18. Carlsson F, Merlo J, Östergren P-O, Lithman T. Representativity of a postal public health questionnaire survey in Sweden, with special reference to ethnic differences in participation. Scand J Public Health. 2006;34:132–9.
19. Carlsson F, Karlson B, Orbaek P, Osterberg K, Ostergren PO. Prevalence of annoyance attributed to electrical equipment and smells in a Swedish population, and relationship with subjective health and daily functioning. Public Health. 2005;119:568–77.
20. Goldberg DP, Blackwell B. Psychiatric illness in general practice: a detailed study using a new method of case identification. Br Med J. 1970;1:439–43.
21. Trafik, människor och miljö i Skåne [Traffic, people and the environment in Scania]. Lund (Sweden): GIS Centre at Lund University; 2005.
22. Bendtsen H. The Nordic prediction method for road traffic noise. Sci Total Environ. 1999;235:331–8.
23. Jonasson H, Kragh J, Parmanen J, Sandberg U, Storeheier S. Road traffic noise—Nordic prediction method. Copenhagen (Denmark): Nordic Council of Ministers; 1996. TemaNord 1996:525.
24. Agresti A. Categorical data analysis. Hoboken (NJ): Wiley; 2002.
25. Thompson ML, Myers JE, Kriebel D. Prevalence odds ratio or prevalence ratio in the analysis of cross sectional data: what is to be done? Occup Environ Med. 1998;55:272–7.
26. Evans GW, Kantrowitz E. Socioeconomic status and health: the potential role of environmental risk exposure. Annu Rev Public Health. 2002;23:303–31.
27. Hoffman B, Robra BP, Swart E. Bundesgesundheitssurvey (Social inequality and noise pollution by traffic in the living environment—an analysis by the German federal health survey; in German with an abstract in English). Gesundheitswesen. 2003;65:393–401.
28. Kruize H, Bouwmann A. Environmental (in)equity in the Netherlands: a case study on the distribution of environmental quality in the Rijnmond region. Bilthoven (Netherlands): Rijksinstituut voor Volksgezondheid en Milieu (RIVM), 2004. RIVM report 550012003/2004.
29. Brainard J, Jones A, Bateman I, Lovett A. Modeling environmental equity: exposure to environmental urban noise pollution in Birmingham, UK. Norwich (UK): Center for Social and Economic Research on the Global Environment, 2003. Working paper 0967–8875; EDM 03–04.
30. Belojevic G, Jakovljevic B, Slepcevic V. Noise and mental performance: personality attributes and noise sensitivity. Noise Health. 2003;6:77–89.
31. Belojevic G, Ohrstrom E, Rylander R. Effects of noise on mental performance with regard to subjective noise sensitivity. Int Arch Occup Environ Health. 1992;64:293–301.
32. Waye KP, Bengtsson J, Rylander R, Hucklebridge F, Evans P, Clow A. Low frequency noise enhances cortisol among noise sensitive subjects during work performance. Life Sci. 2002;70:745–58.
33. Okura Y, Urban LH, Mahoney DW, Jacobsen SJ, Rodeheffer RJ. Agreement between self-report questionnaires and medical record data was substantial for diabetes, hypertension, myocardial infarction and stroke but not for heart failure. J Clin Epidemiol. 2004;57:1096–103.
34. Tormo MJ, Navarro C, Chirlaque MD, Barber X. Validation of self diagnosis of high blood pressure in a sample of the Spanish EPIC cohort: overall agreement and predictive values. J Epidemiol Community Health. 2000;54:221–6.
35. Haapanen N, Miilunpalo S, Pasanen M, Oja P, Vuori I. Agreement between questionnaire data and medical records of chronic diseases in middle-aged and elderly Finnish men and women. Am J Epidemiol. 1997;145:762–9.
36. Brenner H, Savitz DA, Gefeller O. The effects of joint misclassification of exposure and disease on epidemiologic measures of association. J Clin Epidemiol. 1993;46:1195–202.
37. Olivius G, Ostergren PO, Hanson BS, Lyttkens CH. Parental economic stress: evidence of an overlooked public health risk among Swedish families. Eur J Public Health. 2004;14:354–60.

Received for publication: 30 November 2005

Appendix 1

Measures of sound (noise) level

All measures of sound pressure level referred to in this article are A-weighted, which rates sound levels at different frequencies in a way that mimics the sensitivity of the human hearing organ (1). Sound level is expressed in dB(A). In order to average time-fluctuating sound, the equivalent sound level is used, which is the corresponding steady noise level in a predefined time period that contains the same noise pressure as the fluctuating noise during the same time period.

$L_{Aeq,24}$	Equivalent sound level over 24 hours
L_{dn}	Equivalent sound level over 24 hours when sound levels during the night (2300 – 0700) is increased by 10 dB(A), since noise during the night is usually perceived as more annoying.
L_{Afmax}	Defined as the sound level exceeded by the loudest 5% of the vehicles passing a specific road segment. Fast time weighting is applied, which means that the sound level is obtained by integrating the instant sound level over a narrow time period (125 milliseconds).

Appendix 2

Questions about annoyance from traffic noise in the public health survey

Are you annoyed by noise from road traffic, trains or aircraft?

1) Road traffic
    - Not at all
    - Not much
    - Fairly much
    - Much

2) Train noise
    - Not at all
    - Not much
    - Fairly much
    - Much

3) Aircraft noise
    - Not at all
    - Not much
    - Fairly much
    - Much