CLINICAL RESEARCH
Prevention and epidemiology

Road traffic noise and stroke: a prospective cohort study

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Aims	Epidemiological studies suggest that long-term exposure to road traffic noise increases the risk of cardiovascular disorders. The aim of this study was to investigate the relation between exposure to road traffic noise and risk for stroke, which has not been studied before.
Methods and results	In a population-based cohort of 57 053 people, we identified 1881 cases of first-ever stroke in a national hospital register between 1993–1997 and 2006. Exposure to road traffic noise and air pollution during the same period was estimated for all cohort members from residential address history. Associations between exposure to road traffic noise and stroke incidence were analysed in a Cox regression model with stratification for gender and calendar-year and adjustment for air pollution and other potential confounders. We found an incidence rate ratio (IRR) of 1.14 for stroke [95% confidence interval (CI): 1.03–1.25] per 10 dB higher level of road traffic noise (L_{den}). There was a statistically significant interaction with age ($P < 0.001$), with a strong association between road traffic noise and stroke among cases over 64.5 years (IRR: 1.27; 95% CI: 1.13–1.43) and no association for those under 64.5 years (IRR: 1.02; 95% CI: 0.91–1.14).
Conclusion	Exposure to residential road traffic noise was associated with a higher risk for stroke among people older than 64.5 years of age.
Keywords	Stroke • Traffic noise • Epidemiology

Introduction

Increasing noise from traffic occurs in parallel with urbanization. Acute exposure to noise is believed to activate the sympathetic and endocrine systems, thereby causing changes in blood pressure and heart rate and release of stress hormones.[1–3] Furthermore, exposure to noise during the night at normal urban levels has been associated with sleep disturbances.[4]

Persistent exposure to noise is believed to increase the risk of cardiovascular disorders. An overview from 2006 of 61 epidemiological studies of the effects of exposure to transport noise (road, air, and rail) on cardiovascular health showed associations with hypertension and ischaemic heart disease in adults.[5] Recently, a

meta-analysis indicated that the risk for myocardial infarction with road traffic noise increased in a dose–effect manner[6]; this finding was supported by those of a case–control study that, as the first study of its kind, adjusted for exposure to air pollution.[7]

Stroke is a major cause of disability and death worldwide.[8] There has been no investigation of the relation between exposure to transport noise and risk for stroke, although some of the suspected effects of noise, e.g. increased blood pressure, are associated with risk for stroke.[9] One study of the relation between exposure to road traffic noise and overall cerebrovascular mortality showed no association.[10]

The aim of the present study was to investigate the association between exposure to transport noise and risk for stroke in a

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cohort after adjustment for air pollution and other important risk factors for stroke.

Methods

Study population

The study was based on the Diet, Cancer, and Health cohort study in which 160 725 people were invited to participate between 1993 and 1997. The 160 725 people was a random sample of all eligible people living in the Copenhagen or Aarhus area that was free of cancer and between 50 and 64 years of age at the time of invitation. Participants had to have been born in Denmark.[11] All in all, 57 053 people accepted the invitation and were enrolled into the cohort. Participation was based on written informed consent. The study was conducted in accordance with the Helsinki Declaration and approved by the local Ethics Committees.

At enrolment, each participant completed self-administered, interviewer-checked, questionnaires regarding lifestyle habits, diet, health status, and social factors. The average amount of tobacco smoked each day (smoking intensity) was calculated by equating a cigarette to 1 g, a cheroot or a pipe to 3 g, and a cigar to 5 g of tobacco. In the food frequency questionnaire, participants were asked how often on average they had consumed different types of foods during the preceding 12 months. The frequency consumption was categorized into 12 groups ranging from never to 8 or more times daily. A mean daily intake of foods (g/day) was calculated by multiplying the frequencies of intake by a gender-specific portion size using the software Foodcalc version 1.3.[12] Participants were also asked to state their average amount of alcohol consumption as the intake of specific amounts of each beverage type: light, normal, and fortified beer; red, white, and fortified wine; and spirits. On the basis of ethanol content in the different beverage types, these categories were converted into number of standard drinks (12 g alcohol) and added to yield a measure of average gram alcohol per day. Coffee consumption (filter coffee) was also stated and based on this we defined four categories: ≤ 1, $2-3$, $4-5$, and ≥ 6 cups of coffee per day. Trained staff measured height, weight, and diastolic and systolic blood pressures.

Identification of outcome

Stroke events among participants were identified by linking the unique personal identification number of each cohort member to the Danish National Hospital Registry, which has collected nationwide data on all non-psychiatric hospital admissions since 1977. Since 1995, patients discharged from emergency departments and outpatient clinics have also been registered.[13] The Danish National Board of Health maintains the register and assures the quality of the data. We identified cohort members who were registered with a discharge diagnosis of stroke (International Classification of Diseases, revision 8 codes 431.0, 431.9, 432.0, 432.9, 433.09, 433.99, 434.09, 434.99, 436.0, and 436.9 and International Classification of Diseases, revision 10 codes DI61, DI63, and DI64). We only included cases for whom stroke was the primary reason for hospitalization, also when the primary stroke resulted in death. Participants with a discharge diagnosis of stroke before enrolment into the Diet, Cancer, and Health cohort were excluded ($n = 542$). The first hospitalization for stroke was used as the outcome.

Exposure assessment

A complete residential address history was collected between enrolment and event or censoring date for 53 162 of the 57 053 cohort members. Exposure to road traffic noise was calculated for the years 1990, 1995, 2000, and 2005 using Soundplan (version 6.5, http://www.soundplan.dk/) for all 61 873 residential addresses at which these 53 162 cohort members had lived between enrolment and event/censoring. This noise calculation programme implements the joint Nordic prediction method for road traffic noise, which has been the standard method for noise calculation in Scandinavia during many years.[14,15]

The input variables for the noise model were point for noise estimation (geographical coordinates and height of the floor of the residence); road lines, with information on yearly average daily traffic, traffic composition, traffic speed, and road type (motorways, rural highways, roads wider than 6 m, and other roads); and building polygons for all buildings, including information on height. We assumed that the terrain was flat, which is a reasonable assumption in Denmark, and that urban areas, roads, and areas with water were hard surfaces whereas all other areas were acoustically porous. No information was available on noise barriers.

Road traffic noise was calculated as the equivalent continuous A-weighted sound pressure level (L_{Aeq}) at the most exposed facade of the dwelling at each address for the day (L_d; 07:00–19:00 h), evening (L_e; 19:00–22:00 h), and night (L_n; 22:00–07:00 h) and expressed as L_{den} (as an indicator of the overall noise level during the day, evening, and night) by applying a 5 dB penalty for the evening and a 10 dB penalty for the night.[16]

We aimed at investigating effects of relatively recent exposure in our main analyses. Therefore, the noise level used in the analyses was the yearly mean exposure at a residence at a given age.

Exposure to railway noise was calculated with the joint Nordic prediction method based on general information about traffic in 1993–2000. Screening by designated noise screens and buildings was not considered. The noise impact from airports and airfields was determined from information about noise zones obtained from local environmental authorities. The programmes DANSIM and INM3, which fulfil the joint Nordic criteria for air traffic noise calculations, were used.

The curves for railway and aircraft noise were transformed into digital maps, and noise levels were linked to each address by geocodes. In the statistical analysis, exposure to noise from railways and airports was entered categorically as above and below L_{Aeq} 60 dB and L_{den} 55 dB, respectively. Different exposure thresholds were chosen because annoyance and sleep disturbance are greater with airport noise than with railway noise.[4,17] About 17% of the cohort members were exposed to railway noise in excess of 60 dB, and 1% was exposed to aircraft noise above 55 dB.

The concentration of NO_x in the air was calculated with the Danish AirGIS modelling system for each year (1993–2006) at each address at which the cohort members had lived. AirGIS allows calculation of air pollution at a location as the sum of: local air pollution from traffic in the streets, with the Operational Street Pollution Model; the urban background contribution, calculated with a simplified area source dispersion model (SUBmodel); and a regional background contribution.[18] Input data for the AirGIS system included traffic data for the period 1960–2005, emission factors for the Danish car fleet, street and building geometry, building height, and meteorological data.[19] The AirGIS system has been successfully validated in several studies.[18–20]

We calculated the yearly mean exposure for noise and NO_x from 1993 to 2006 for all addresses for which we had information on. Based on this, we determined the difference in noise and NO_x means, respectively, over time.

Statistical methods

The analyses were based on a Cox proportional hazards model with age as the underlying time.[21] This ensured comparison of individuals of the same age. We used left truncation at the age of enrolment, so that people were considered at risk from enrolment into the cohort, and right censoring at the age of stroke (event), death, emigration, or end of follow-up (27 June 2006), whichever came first (event/censoring). All analyses were stratified by gender and calendar-year. Exposure to road traffic noise was modelled as a time-dependent variable using the value of the yearly mean exposure at the residence at a given age.

The incidence rate ratios (IRRs) for stroke in association with road traffic noise at the time of diagnosis were calculated as crude estimates and adjusted for *a priori* defined potential confounders. Information on most potential confounders was based on the baseline questionnaire: smoking status (never, former, current), smoking intensity (g tobacco/day), intake of fruit (g/day), intake of vegetables (g/day), education (<8, 8−10, >10 years), alcohol intake (yes/no; g/day among drinkers), body mass index (BMI, kg/m^2), and physical activity (yes/no; h/week of sport during leisure time among active). The remaining covariates were based on address-specific information on: municipality income (data from 1995; 10th and 90th percentiles of the mean gross income of the 275 Danish municipalities as cut-off points); railway and airport noise [mainly based on data from the late 1990s (railway noise >60 dB (yes/no) and airport noise >55 dB (yes/no))]; and air pollution (NO$_x$, µg/m^3, data on exposure at the residence in the period from 1993 to 2006). Information on all the selected potential confounders was available for 51 485 of the 53 162 cohort members with complete residential histories. Estimates were calculated both with and without further adjustment for systolic and diastolic blood pressures and use of antihypertensive medicine at the time of enrolment.

We also conducted an analysis in which we calculated the IRRs for stroke in association with road traffic noise at the residential address at the time of enrolment (baseline).

The assumption of linearity of the variables (traffic noise, air pollution, smoking intensity, intake of fruits, intake of vegetables, alcohol consumption, BMI, and blood pressure) in relation to risk for stroke was evaluated both visually and by formal testing with linear spline models with boundaries placed at the nine deciles for cases.[22] Traffic noise, smoking intensity, and diastolic and systolic blood pressures did not deviate significantly from linearity and were entered as linear variables. Air pollution was included as a linear variable after logarithmic transformation. Intake of fruits, intake of vegetables, intake of alcohol, and BMI were included as linear variables after allowance for different slopes below and above 100, 150, and 15 g/day and 24 kg/m^2, respectively. These cut-points were determined by visual examination of the linear spline models, followed by a formal testing of whether we could assume linearity of the variables below and above the cut-points.

In addition to the linear analyses described earlier, we performed a categorical analysis with seven noise exposure categories (55−58, 58−61, 61−64, 64−67, 67−70, 70−73, and >73 dB) and a reference category (≤55 dB). We used 55 dB as the reference because this is often the limit value for noise in outdoor residential areas, and we used exposure categories of 3 dB because this difference corresponds to a doubling in acoustical energy. IRRs above and below 64.5 years of age, corresponding to the median age at stroke diagnosis among the cases, were calculated. IRRs were also calculated separately for men and women and for cases with and without co-morbidity of acute myocardial infarction and of diabetes at the time of the stroke diagnosis.

All tests were based on the likelihood ratio test statistic. Two-sided 95% confidence intervals (CIs) were calculated on the basis of the Wald test of the Cox regression parameter, that is, on the log ratio scale. The procedure PHREG in SAS version 9.1 (SAS Institute, Cary, NC, USA) was used for the statistical analyses.

Results

Out of the study population of 51 485 participants, 1881 (3.7%) were admitted to hospital for stroke for the first time between baseline and censoring, with an average follow-up of 6.0 years among cases and 10.1 among cohort members. Distribution of baseline covariates and air pollution among the cohort according to exposure to road traffic noise below and above 60 dB can be seen in Table 1.

The distribution of road traffic noise exposure (L_{den}) at enrolment into the cohort is shown in Figure 1. There was a significant correlation between L_{den} and NO$_x$ at enrolment ($r = 0.62$, $P < 0.0001$). During the period from 1993 (inclusion) to 2006 (end of follow-up), there was a small but steady increase over time in L_{den} for the addresses used in this study (approximately 0.5 dB increase per 5 years). For NO$_x$, the concentration decreased approximately 25% from 1993 to 2000 after which it stabilized.

A 10 dB higher level of road traffic noise was associated with a 1.14 times (95% CI: 1.03−1.25) higher risk for stroke after adjustment for various risk factors (Table 2). The association was still present after further adjustment for systolic and diastolic blood pressures and use of antihypertensive medicine at enrolment (IRR: 1.12; 95% CI: 1.01−1.24). For participants above 64.5 years of age, the IRR was 1.23 (95% CI: 1.09−1.39) and for participants below 64.5 years of age, the IRR was 1.01 (95% CI: 0.89−1.15) after adjustment for blood pressure and antihypertensive medicine. Similar IRRs were found for men and women (Table 2). There was a significant interaction with age ($P < 0.001$), with a strong association between road traffic noise and stroke among older cases (≥64.5 years) and no association in younger cases. The exposure to noise was similar in participants below and above 64.5 years of age (mean: 57.8 and 58.2 dB, respectively). There were no statistically significant interactions with co-morbidity, neither acute myocardial infarction nor diabetes (Table 2). Also, no interactions with co-morbidity were found in participants below or above 64.5 years, respectively (all P for the interactions >0.64, data not shown).

In an analysis in which baseline exposure was used as noise exposure variable, we found an IRR of 1.07 (95% CI: 0.98−1.18) per 10 dB higher noise exposure at the residence at enrolment (adjusted analysis).

Figure 2 shows the IRRs for seven exposure categories in comparison with a reference group of ≤55 dB for participants below and above 64.5 years of age. For the younger participants, there were no associations between road traffic noise and risk for stroke, except in the highest exposure group (>73 dB) in which there seemed to be an association (IRR: 1.48; 95% CI: 0.98−2.24; Figure 2A). Among the older participants, there were some indications of an increase in the risk for stroke at road traffic noise levels <60 dB. At exposures >60 dB, the risk for stroke increases in what seemed to be a dose-dependent manner

Table 1 Baseline characteristics for the Diet, Cancer, and Health cohort according to exposure to road traffic noise below and above 60 dB (L_{den})

Characteristics at enrolment	$L_{den} \leq 60$ (n = 33 843)		$L_{den} > 60$ (n = 17 642)	
	n (%)	Median (5–95th percentiles)	n (%)	Median (5–95th percentiles)
Gender				
Male	16 279 (48)		8029 (46)	
Female	17 564 (52)		9613 (54)	
Age (years)		56.1 (50.7–64.1)		56.3 (50.8–64.2)
Smoking				
Current	11 404 (34)		7288 (41)	
g tobacco/day		15.0 (4.8–31.7)		15.3 (5.3–32.3)
Former	9523 (28)		4651 (26)	
Never	12 916 (38)		5703 (32)	
Intake of fruits (g/day)		172 (29–517)		163 (24–537)
Intake of vegetables (g/day)		165 (51–366)		155 (45–369)
Years of education				
≤ 7	10 624 (31)		6368 (36)	
8–10	15 774 (47)		8080 (46)	
>10	7445 (22)		3194 (18)	
Municipality income				
Low	4414 (13)		6385 (36)	
Medium	20 954 (62)		6756 (38)	
High	8475 (25)		4501 (26)	
Physical activity				
No	14 779 (44)		8813 (50)	
Yes	19 064 (56)		8829 (50)	
Among active (h/week)		2.0 (0.5–6.5)		2.0 (0.5–7.0)
BMI (kg/m^2)		25.4 (20.5–33.1)		25.7 (20.32–33.9)
Drink alcohol				
No	680 (2)		484 (3)	
Yes	33 163 (98)		17 158 (97)	
Among active drinkers (g/day)		13.3 (1.2–62.2)		13.2 (1.0–69.3)
Intake of coffee (cups/day)				
≤ 1	5646 (17)		3074 (17)	
2–3	9126 (27)		4723 (27)	
4–5	9685 (29)		4819 (27)	
≥ 6	9386 (28)		5026 (28)	
Air pollution (NO$_x$, μg/m^3)		18.5 (14.1–28.3)		34.3 (16.9–137)

(*Figure 2B*). At enrolment, 35% of the cohort members lived at addresses with noise levels >60 dB.

We found that a doubling in NO$_x$ was associated with an IRR of 1.04 (95% CI: 0.98–1.10) when adjusted for the selected potential confounders (lifestyle confounders, education, and municipality income) except traffic, railway, and airport noise and an IRR of 0.96 (95% CI: 0.88–1.04) when adjusted by all the selected potential confounders including noise. A 10 dB higher level of road traffic noise was associated with a 1.10 times (95% CI: 1.03–1.18) higher risk for stroke after adjustment for all the selected potential confounders except NO$_x$.

Exposure to railway and airport noise was not associated with a higher risk for stroke (IRR railway: 1.04; 95% CI: 0.92–1.17 and IRR airport: 0.73; 95% CI: 0.39–1.37). The IRR for stroke mortality (survival 30 days or less after a stroke; 146 of 1881 cases) was 1.09 (95% CI: 0.86–1.39).

Discussion

In this study, residential exposure to road traffic noise was associated with risk for stroke, with a 14% higher risk per 10 dB higher
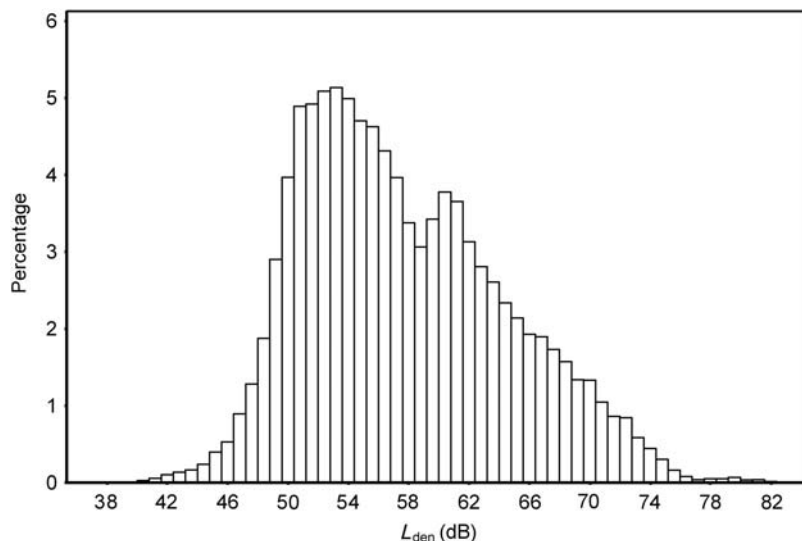
Figure 1 Distribution of residential exposure to road traffic noise (L_{den}) at the time of enrolment into the cohort.

Table 2 Incidence rate ratios (IRRs) of stroke per 10 dB higher level of exposure to road traffic noise

Exposure to road traffic noise, L_{den} (per 10 dB)	No. of cases	Crude IRR (95% CI[a])[b]	P-value	Adjusted IRR (95% CI[a])[c]	P-value	P-interaction
All	1881	1.18 (1.11–1.26)	<0.0001	1.14 (1.03–1.25)	0.008	
Gender						0.96
Male	1109	1.20 (1.10–1.30)	<0.0001	1.14 (1.02–1.27)	0.02	
Female	772	1.17 (1.05–1.29)	0.003	1.13 (1.00–1.28)	0.04	
Age at stroke (years)						0.001
<64.5	952	1.06 (0.97–1.16)	0.22	1.02 (0.91–1.14)	0.77	
≥64.5	929	1.32 (1.20–1.45)	<0.0001	1.27 (1.13–1.43)	<0.0001	
Co-morbidity, acute myocardial infarction[d]						0.80
Yes	143	1.22 (0.97–1.53)	0.10	1.17 (0.92–1.48)	0.21	
No	1738	1.18 (1.10–1.26)	<0.0001	1.13 (1.03–1.24)	0.01	
Co-morbidity, diabetes[d]						0.75
Yes	244	1.20 (1.01–1.43)	0.04	1.16 (0.96–1.40)	0.12	
No	1637	1.17 (1.09–1.26)	<0.0001	1.13 (1.02–1.24)	0.02	

[a]CI, confidence interval.
[b]Stratified by gender.
[c]Stratified by gender and calendar-year and adjusted for lifestyle confounders (smoking status, smoking intensity, intake of fruits, intake of vegetables, intake of coffee, BMI, alcohol intake, and physical activity), education, municipality income, exposure to noise from railways and airports, and exposure to air pollution (NO_x).
[d]A previous diagnosis at the time of the stroke diagnosis.

exposure to noise for all participants and a 27% higher risk per 10 dB higher exposure to noise for participants above 64.5 years.

This is the first study on the association between transport noise and risk for stroke, as previous studies on transport noise focused mainly on hypertension and ischaemic heart disease.[5] Exposure to noise is suspected to cause hypertension and ischaemic heart disease through a stress response, with changes in stress hormones and blood pressure,[1–3] which are also related to the risk for stroke.[9] Our results show that the risk for stroke increases in a dose-dependent manner at exposure levels > 60 dB among the oldest participants. These results are in accordance with the results of a meta-analysis of case–control and cohort studies on road traffic noise and myocardial infarction, which showed that there appeared to be a dose–response relation starting at noise levels > 60 dB.[6]
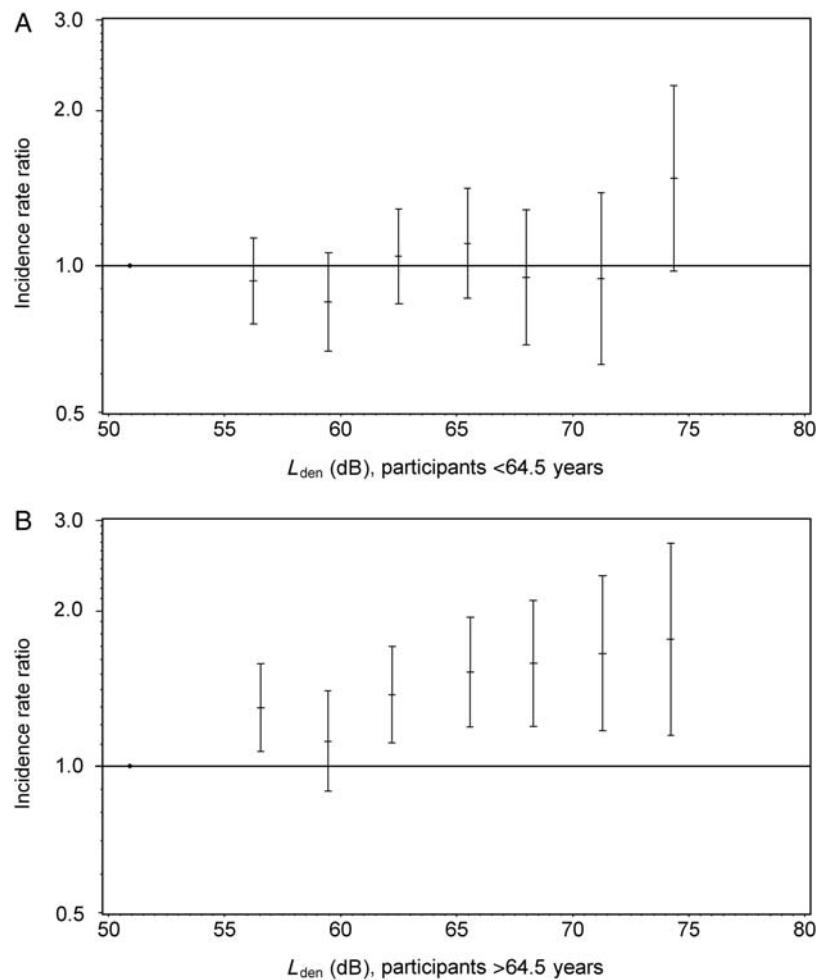
Figure 2 Dose−response relation between exposure to road traffic noise (L_{den}) and incidence rate ratio (IRR) for stroke based on a Cox proportional hazards model with age as the underlying timescale among participants below (*A*) and above (*B*) 64.5 years of age. The analyses were stratified by gender and calendar-year and adjusted for smoking status and intensity, intake of fruits, intake of vegetables, intake of coffee, body mass index, alcohol intake, physical activity, education, municipality income, exposure to noise from railways and airports, and exposure to air pollution (NO_x). The vertical whiskers show the IRRs with 95% confidence intervals at the median of seven exposure categories (55−58, 58−61, 61−64, 64−67, 67−70, 70−73, and >73 dB) when compared with the reference category of ≤55 dB. The black dot shows the median of the reference category. The horizontal solid line shows the neutral value (IRR = 1.0).

This value may therefore be a threshold with regard to both cerebro- and cardiovascular effects of road traffic noise.

Although one of the most important risk factors for stroke is high blood pressure,[9] the association with road traffic noise persisted after adjustment for systolic and diastolic blood pressures and use of antihypertensive medicine, indicating that other pathways are involved in the effect of traffic noise on risk for stroke.

If we assume that the association in the categorical analyses among all participants is causal, an estimated 8% of all stroke cases (19% of stroke cases more than 64.5 years of age) in this population could be attributed to exposure to road traffic noise. The population in this study, however, lived mainly in urban areas and is thus not representative of the whole population in terms of exposure to road traffic noise.

In the present study, we focused on relatively recent exposure as we used annual means of noise at the residences in our main analyses. In another analysis, we found that exposure to noise more distant in time (at enrolment) was associated with a 7% higher risk for stroke per 10 dB higher exposure to noise, which suggests that recent exposures are more strongly associated to stroke than more distant exposure to noise. However, as 72% of the participants in our study did not move during the follow-up period, it is difficult to separate the effect of recent and distant noise exposures, and, thus, exposure to noise more distant in time might also affect the risk for stroke.

The relation between exposure to road traffic noise and risk for stroke was strongest among the oldest participants in the present study. Sleep disturbances can contribute to cerebro- and cardiovascular risks,[23,24] leading to the hypothesis that nocturnal exposure to noise might be more harmful than daytime exposure.[25] The sleep structure generally becomes more fragmented with age, and elderly people are thus more susceptible to sleep

disturbances.[26,27] This could explain why the association between road traffic noise and risk for stroke was mainly seen for the oldest participants. As exposure to road traffic noise during the night (L_n) was highly correlated with L_{den}, we could not separate the two effects.

The study indicated no association between risk for stroke and noise from railways and airports; however, the risk estimate for exposure to airport noise has a very wide CI (0.39–1.37) probably because <1% of the cohort was exposed. Furthermore, the calculations of railway noise were subject to some degree of uncertainty because of missing information on screening by buildings and noise screens. Thus, we cannot rule out the possibility that these types of noise also affect the risk for stroke.

An important strength of our study is the adjustment for air pollution, which is known to correlate with road traffic noise and, thus, could confound the association between noise and stroke. We used NO_x levels as an indicator of air pollution, because NO_x is a good marker of traffic-related air pollution and correlates closely with particulate matter in Danish streets: $r = 0.93$ for total particle number concentration [size 10–700 nm (ultrafine particles)] and $r = 0.70$ for PM_{10}.[28,29] The role of air pollution as a trigger of stroke following short-term exposures is well established,[30–33] whereas still limited and mixed evidence exists on the effect of long-term exposures to air pollution on the risk of developing stroke.[34,35] We found that exposure to air pollution was not associated with risk for stroke neither before nor after adjustment for traffic noise. Our definition of air pollution exposure as annual-mean NO_x levels at the time of the stroke admission likely represents a mix of short- and long-term effects of air pollution. Exposure to road traffic noise, however, was significantly associated with risk for stroke both before and after adjustment by air pollution, suggesting an independent effect of road traffic noise.

The strengths of our study also include the prospective design, follow-up for stroke in a nationwide register, the large number of cases, and access to residential address histories. Furthermore, we considered only the first hospitalization for stroke, reducing any influence of preventive medication on the risk estimates.

The estimation of noise was based on modelled and not measured values. In addition to practical and economical advantages of the modelling approach in large-scale epidemiological studies, the modelling approach might provide the best noise estimate. The level of traffic noise varies over very short time due to, for example, the movement of vehicles relative to the observer and strong influence of the propagation of traffic noise by weather. It is therefore extremely difficult, if not impossible, to get reliable long-term noise exposure data by use of direct measurements, and during the last four decades, still more accurate and reliable prediction methods for traffic noise have, thus, been developed. However, although the Nordic prediction method has been used for many years, estimation of noise is inevitably associated with some degree of uncertainty. One reason could be inaccurate input data, which would result in exposure misclassification. As the noise model does not distinguish between cases and the cohort, such misclassification is believed to be non-differential, and, in most situations, this would influence the relative risk estimate towards the neutral value. Air pollution levels were calculated with dispersion models that have been successfully validated and applied.[18,20,36] Nevertheless, as for noise, such estimates are associated with some degree of uncertainty; it is possible that some of the effects found for exposure to road traffic noise can be explained by residual confounding from air pollution.

Another limitation is that we had information only on residential addresses and not, for example, work or holiday home addresses. Such an imprecision is, however, believed to have been similar for cases and the cohort and might therefore have attenuated the risk estimates. We also had no information on bedroom location, window opening habits, noise from neighbours, or hearing impairment, all of which might influence exposure to noise. Other studies have found that the association with noise is stronger when these factors are considered,[5,7] suggesting that the effect of noise might be underestimated in the present study.

The stroke cases were identified from a national register instead of from medical records, which is another limitation. Previous validation studies of the register have showed, however, that approximately 80% of persons with a diagnosis of stroke in the Danish National Hospital Registry are confirmed when medical records are reviewed.[37,38] The predictive value of the register is thus high, and we believe that diagnostic errors would have affected the risk estimates only marginally.

In the present study, the analyses were adjusted by various potential lifestyle and socio-economic confounders, as well as by air pollution. We cannot, however, rule out that confounders not accounted for or residual confounding could affect the results. For example, we find a higher proportion of participants with low income among the highly exposed when compared with participants exposed to <60 dB, and socio-economic status has been found to be a predictor for stroke.[39] Therefore, we cannot exclude the possibility of residual confounding by socio-economic differences.

Conclusions

The present study shows a positive association between residential exposure to road traffic noise and risk for stroke in a general Danish population among people older than 64.5 years of age. As this is the first study of its kind, the results need to be confirmed by other studies before any conclusions can be drawn.

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