



Residential exposure to traffic noise and risk for non-hodgkin lymphoma among adults



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ABSTRACT

Exposure to traffic noise may result in stress and sleep disturbances, which have been associated with impairment of the immune system. People with weakened immune systems are known to have a higher risk for non-Hodgkin lymphoma (NHL). We aimed to determine whether traffic noise was associated with risk for NHL in a nationwide case-control study. We identified 2753 cases aged 30–84 years with a primary diagnosis of NHL in Denmark between 1992 and 2010. For each case we selected two random population controls, matched on sex and year of birth. Road traffic and railway noise were calculated, and airport noise was estimated for all present and historical residential addresses of cases and controls from 1987 to 2010. Associations between traffic noise and risk for NHL were estimated using conditional logistic regression, adjusted for disposable income, education, cohabiting status and comorbidity. We found that a 5-year time-weighted mean of road traffic noise above 65 dB was associated with an 18% higher risk for NHL (95% confidence interval (CI) 1.01–1.37) when compared to road traffic noise below 55 dB, whereas for exposure between 55 and 65 dB no association was found (odds ratio: 0.98; 95% CI: 0.88–1.08). In analyzes of NHL subtypes, we found no association between road traffic noise and risk for T-cell lymphoma, whereas increased risks for B-cell lymphoma and unspecified lymphomas were observed at exposures above 65 dB. In conclusion, our nationwide study may indicate that high exposure to traffic noise is associated with higher NHL risk.

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1. Introduction

Non-Hodgkin lymphoma (NHL) is a diverse group of malignancies originating from lymphoid tissue. Though incidence rates have more than doubled since 1960, with stabilization around year 2000 (Sandin et al., 2006), the etiology of most types of NHL remains largely unknown. One well-established risk factor is suppression of the immune system (Shankland et al., 2012), and several studies have shown an increased risk of NHL among HIV patients, organ recipients receiving immunosuppressive drugs and patients with autoimmune diseases (Fallah et al., 2014; Grulich et al., 2007). In addition, a growing number of studies have indicated that genetic variants related to the immune system, including immune recognition and regulation, is associated with increased risk for NHL (Carvalho et al., 2012; Cerhan et al., 2014; Nieters et al., 2011). Also, circadian genes have been associated with NHL, possibly through their influence on immune regulation

(Hoffman et al., 2009), and some epidemiological studies have indicated that night-shift workers are at higher risk for NHL (Lahti et al., 2008; Parent et al., 2012). Due to the apparent strong relationship between the immune system and development of NHL, it is conceivable that also more moderate disturbances of the immune system may increase the risk for NHL.

Exposure to traffic noise has been associated with cardiovascular disease and diabetes (Babisch, 2014; Sorensen et al., 2013a). One of the proposed mechanisms is disturbance of sleep, as nighttime exposure to traffic noise at normal urban levels has been associated with sleep disturbances, including short sleep duration and reduced sleep quality (Basner et al., 2011; Miedema and Vos, 2007). Sleep is known to have a strong regulatory influence on the immune system (Ali and Orr, 2014; Gomez-Gonzalez et al., 2012), and deprivation of sleep has been associated with impairment of the immune system, e.g. reduced post-vaccination antibody titers have been demonstrated following sleep restriction at the night after vaccination (Lange et al., 2003; Spiegel et al., 2002). Sleep deprivation has also been associated with various aberrations in the immune system, including changed numbers of circulating white blood cells and increased production of pro-inflammatory

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molecules (Aho et al., 2013; Irwin et al., 2006, 2008).

Another potential adverse health effect of noise is that traffic noise can trigger a stress response, causing hyperactivity of the sympathetic autonomic nervous system, activation of the hypothalamus–pituitary–adrenal axis and increased levels of cortisol (Munzel et al., 2014; Selander et al., 2009a). It is also possible that noise-induced stress may affect the immune system, as some studies have suggested that exposure to various acute and chronic stressors, e.g. exams and stressful life events, is associated with an impaired immune system (Segerstrom and Miller, 2004).

In the present nationwide case–control study, we aimed to assess the association between exposure to traffic noise and risk for NHL within the adult population of Denmark.

2. Methods

2.1. Study population

Cases were identified using the Cancer Registry (Gjerstorff, 2011). Eligible cases were Danes between 30 and 84 years of age with a primary diagnosis of NHL between 1992 and 2010. NHL cancer diagnoses were identified as morphology codes 9590–9596 and 9670–9729 according to the third edition of International Classification of Diseases for Oncology (ICD-O-3) (World Health Organization, 2000). We further required that cases were born in Denmark, had no previous diagnosis of cancer (except non-melanoma skin cancer), and lived at a geocodable address in Denmark at the time of diagnosis.

For each case two random controls, matched on sex and year of birth, were selected from the Civil Registration System. Controls which were dead, emigrated or diagnosed with cancer (except non-melanoma skin cancer) before diagnosis date of their matched case were excluded and substitute controls, matched on sex and year of birth, and under risk at age at diagnosis of the matched case, were sampled from surplus controls from the present study as well as from random population controls sampled for other ongoing studies. All controls in the final sample were required to be alive, free of cancer (except non-melanoma skin cancer), born in Denmark and living at a geocodable address in Denmark at time of diagnosis of matched case.

2.2. Socioeconomic position and comorbidity

Following information on individual socioeconomic position (SEP) was obtained by linkage to Statistics Denmark (Baadsgaard and Quitzau, 2011): highest attained education, cohabiting status, and individually disposable income determined as household income after taxation and interest per person, adjusted for number of household persons and divided into quintiles based on Danish background population (age-standardized). Education was assessed at date of diagnosis, whereas the other SEP variables were assessed one year before diagnosis.

Information on comorbidity was obtained from the Danish National Patient Registry, which holds information on all non-psychiatric hospital admissions since 1977 and on all outpatient and psychiatric hospital contacts since 1995 (Lyngé et al., 2011). The data include medical diagnoses (ICD-8 until 1993 and ICD-10 from 1994 onwards), surgical procedures, and date of activity. Using this we generated Charlson Comorbidity index (0, 1 and ≥ 2) for all based on all relevant diagnosis until one year before index date.

2.3. Exposure

Residential address history for all cases and controls between

1987 and index date was collected using the Civil Registration System. Road traffic noise exposure was calculated at the most exposed facade for all present and historical addresses using SoundPLAN, a software implementing the joint Nordic prediction method for road traffic noise (Bendtsen, 1999). Input variables were: geographical coordinate, road links with information on annual average daily traffic, vehicle distribution, travel speed and road type; and building polygons for all Danish buildings. We obtained traffic counts for all Danish roads with more than 1000 vehicles per day from a national database (Jensen et al., 2009). We assumed flat terrain, and that urban areas, roads and areas with water were hard surfaces and all other areas acoustically porous. No information was available on noise barriers. Road traffic noise was expressed as L_{den} (day, evening and night).

Exposure to railway noise was calculated for all addresses using SoundPLAN, with implementation of NORD2000. Input variables were geographical coordinate, railway links with information on annual average daily train lengths, train types, travel speed; building polygons and noise barriers along the railway. Railway traffic noise was expressed as L_{den} at the most exposed facade. The noise impact from all Danish airports and airfields was determined from information about noise zones (5 dB categories) obtained from local authorities and transformed into digital maps and linked to each address.

Ambient air pollution (NO_2) was calculated for each year at each address using AirGIS, which calculates a sum of local, urban and regional contributions (Berkowicz et al., 2008). Input data included traffic data as described above, emission factors, street and building geometry, and meteorological data (Jensen et al., 2009; Ketznel et al., 2011). We used NO_2 as a proxy of traffic-related air pollution as it has been shown to correlate closely with particulate matter, including ultrafine particles and PM_{10} in Danish streets (Ketznel et al., 2003).

2.4. Statistical analyzes

We used conditional logistic regression. For each person, exposure to road traffic noise was modeled as time-weighted 1- and 5-years means preceding index date, taking the complete migration history in these periods into account. The assumption of linearity of road traffic noise was evaluated visually and by linear spline models with boundaries placed at quartiles for cases. We found that the association between road traffic noise and NHL deviated statistically significant from linearity and, therefore, all analyzes were performed using following categories: < 55 , 55–65 and ≥ 65 dB. The reference was set to < 55 dB, as this level is often used in studies of traffic noise and health as a reference cut-point (Babisch, 2014), and the 65 dB cut-point was set to select a group of highly exposed persons ($\approx 90\%$ percentile). For airport and railway noise we used noise exposure at index date address in categories for airport noise of above and below 55 dB and for railway noise in categories of: 0 dB, 0–55 dB and ≥ 55 dB.

We calculated odds ratios (OR) and 95% confidence intervals (CI) for risk for NHL associated with exposure to traffic noise, with adjustment for age and sex (by design), education (basic or high school; vocational education; higher education; unknown), disposable income (quintiles), cohabitation status (married/cohabiting, single, widow/widower or divorced) and Charlson comorbidity index (0, 1 or ≥ 2). In further analyzes, we performed additional adjustment for air pollution. As a *post-hoc* sensitivity analysis, we divided the highest exposure category (above 65 dB) into two categories: 65–70 dB and > 70 dB, and calculated adjusted ORs. ORs were estimated for NHL subtypes: B-cell lymphoma (ICD-O-3: 9670–9699, 9728), T-cell lymphomas (ICD-O-3: 9700–9719, 9729) and unspecified lymphomas (ICD-O-3: 9590–9596, 9727). We used SAS version 9.2 (SAS Institute, North Carolina, USA).

3. Results

From a study population of 7722 individuals, we excluded 124 with missing exposure and five with missing confounders information. After these exclusions, 33 cases had no matching controls and 64 controls had no matching case, and were excluded. The final study population comprised of 7496 individuals; 2753 cases and 4743 controls.

Cases had slightly more comorbidity and were more often cohabiting than controls, whereas SEP was similar between cases and controls (Table 1). The distribution of 5-years exposure to road traffic noise (L_{den}) is shown in Fig. 1. Spearman's correlations were 0.95 for 1-year and 5-years exposure to road traffic noise, and 0.43 for road traffic noise and air pollution (5-years exposure).

A 5-year time-weighted mean of road traffic noise above 65 dB was associated with an 18% higher risk for NHL (95% CI: 1.01–1.37), compared with road traffic noise below 55 dB, whereas for exposure between 55 and 65 dB no association was found (Table 2). Additional adjustment for air pollution yielded slightly higher risk estimates: 1-year and 5-years road traffic noise exposure above 65 dB were associated with ORs of 1.26 (95% CI: 1.05–1.52) and 1.23 (95% CI: 1.02–1.48), respectively. In the *post-hoc* analysis dividing the highest exposure category for road traffic noise into two categories, we found ORs (95% CI: 1.00–1.42; 281 cases) for 65–70 dB and 1.30 (95% CI: 1.01–1.67; 118 cases) for ≥ 70 dB for 1-year exposure; and of 1.18 (95% CI: 1.00–1.40; 106 cases) and 1.17 (95% CI: 0.90–1.51; 288 cases), correspondingly, for the 5-years

Table 1
Characteristics of cases of non-Hodgkin lymphoma and controls

	Cases (n=2753)	Controls (n=4743)
Men	55.7	54.4
Age (years) ^a	62.9 (43.7–79.7)	62.6 (43.8–79.1)
Level of education ^a		
Basic or high school	41.2	40.5
Vocational education	37.0	37.0
Higher education	17.1	17.9
Unknown	4.8	4.7
Disposable income ^{b,c}		
Lowest (1st tertile)	32.5	32.3
Middle (2nd tertile)	33.0	32.4
Highest (3th tertile)	34.5	35.3
Cohabitation status ^b		
Married or cohabiting	66.6	64.8
Single	9.5	9.6
Widow or widower	12.2	12.1
Divorced	11.7	13.5
Charlson comorbidity index ^b		
None	76.1	80.2
1	15.0	12.1
≥ 2	9.0	7.6
Road traffic noise ^d		
< 55 dB	40.1	40.3
55–65 dB	45.6	47.2
≥ 65 dB	14.3	12.5
Railway noise ^a		
0 dB	85.2	84.4
0–55 dB	9.9	10.8
≥ 55 dB	4.9	4.8
Airport noise ^a		
< 55 dB	100	100
≥ 55 dB	0.01	0.004

Values are given as percentage, though for age as medians (5–95 percentiles).

^a At index date.

^b Based on present and past diagnoses one year before index date.

^c Household income 1 year before index date after taxation and interest, adjusted for number of persons in the household and categorized by gender-specific distribution of disposable household income per person.

^d Time-weighted mean 5-years preceding index date.

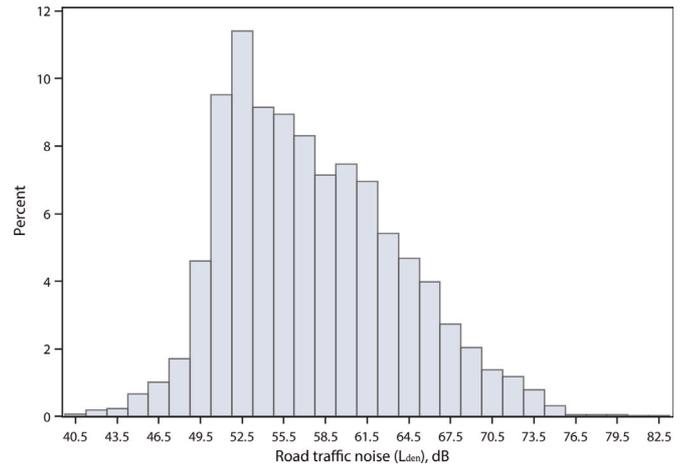


Fig. 1. Distribution of mean residential exposure to road traffic noise (L_{den}) 5-years preceding index date.

Table 2
Associations between exposure to residential traffic noise and risk for non-Hodgkin lymphoma.

	N cases	Crude OR (95% CI) ^{a,b}	Adjusted OR (95% CI) ^{a,c}
Road traffic noise			
<i>1-year exposure^d</i>			
< 55 dB	1133	1.00	1.00
55–65 dB	1221	0.99 (0.90–1.10)	1.00 (0.90–1.10)
≥ 65 dB	399	1.21 (1.04–1.40)	1.22 (1.05–1.42)
<i>5-year exposure^d</i>			
< 55 dB	1103	1.00	1.00
55–65 dB	1256	0.97 (0.88–1.08)	0.98 (0.88–1.08)
≥ 65 dB	394	1.16 (1.00–1.35)	1.18 (1.01–1.37)
Railway noise^e			
0 dB	2345	1.00	1.00
0–55 dB	272	0.88 (0.75–1.03)	0.88 (0.75–1.03)
≥ 55 dB	136	1.04 (0.83–1.29)	1.04 (0.84–1.30)
Airport noise^e			
< 55 dB	2736	1.00	1.00
≥ 55 dB	17	1.35 (0.70–2.61)	1.43 (0.74–2.75)

^a OR, odds ratio; CI, confidence interval.

^b Crude (match on sex and year of birth).

^c Model 1 plus adjustment for disposable income, level of education, cohabiting status, comorbidity, railway noise and airport noise.

^d Time-weighted mean exposure preceding the index date, taking all addresses in that period into account.

^e Yearly mean at the index date address.

mean. No statistically significant associations between exposure to railway or airport noise and risk for NHL were observed.

In analyzes of NHL subtypes, B-cell lymphoma and unspecified lymphoma seemed associated with road traffic noise above 65 dB, whereas no associations were found for T-cell lymphoma (Table 3).

4. Discussion

In our nationwide study we found that exposure to road traffic noise above 65 dB was associated with a statistically, significant higher risk for NHL compared with road traffic noise exposures below 55 dB. In analyzes of NHL subtypes, exposure to road traffic noise above 65 dB seemed associated with increased risk for B-cell lymphoma and unspecified lymphomas.

We are not aware of studies examining the association between traffic noise and NHL. We have previously investigated the association between traffic noise and breast cancer, and found both

Table 3

Associations between 5-year exposure to residential road traffic noise and risk for subtypes of non-Hodgkin lymphoma.

Subtype of NHL	Road traffic noise, 5-years	N cases	OR (95% CI) ^a
B-cell lymphoma	< 55 dB	815	1.00
	55–65 dB	922	0.95 (0.84–1.67)
	≥ 65 dB	290	1.16 (0.97–1.38)
T-cell lymphoma	< 55 dB	96	1.00
	55–65 dB	107	0.95 (0.67–1.37)
	≥ 65 dB	26	0.82 (0.46–1.45)
Lymphomas, NOS ^b	< 55 dB	192	1.00
	55–65 dB	227	1.08 (0.84–1.39)
	≥ 65 dB	78	1.34 (0.94–1.91)

^a Odds ratio with 95% confidence interval with match on sex and year of birth and adjustment for disposable income, level of education, cohabiting status and comorbidity.

^b NOS: Not Otherwise Specified.

road traffic and railway noise to be associated with an increased risk for estrogen receptor negative breast cancer (Sørensen et al., 2013b). Also, a number of studies have reported associations between exposures to traffic noise and cardiovascular disease (Babisch, 2014), with proposed mechanisms through disturbance of sleep, annoyance and stress (Basner et al., 2011; Miedema and Vos, 2007; Selander et al., 2009a). Since disturbance of sleep and stress have also been associated with a weakened immune system (Irwin et al., 2008; Lange et al., 2003; Segerstrom and Miller, 2004), it appears biologically plausible that long-term exposure to traffic noise may also affect diseases in which the immune system plays a central role, e.g. NHL. A few epidemiological studies have reported that nightshift work, representing a massive disturbance of sleep, is associated with increased NHL risk (Lahti et al., 2008; Parent et al., 2012). Also, three studies have examined associations between various noise exposures (occupational and airport) and inflammatory biological markers (Gan et al., 2011; Meier et al., 2014; Schmidt et al., 2013). These studies indicated no or only weak associations. However, only a very limited number of inflammatory markers were investigated and the definition of noise exposure differed markedly.

The present study indicated a non-linear association, where only people exposed to high levels of road traffic noise were at increased risk for NHL. This pattern, together with the explorative character of our study, dictates that our results should be treated with caution. Our findings would be strengthened if there were indications of an exposure–response relationship at noise levels above 65, and we, therefore, conducted a *post-hoc* analysis dividing the highest exposure category into two categories. The results were not easily interpretable, because for the 1-year road traffic noise mean there was an indication of a dose–response relationship, whereas this was not observed for the 5-year mean. It would also strengthen our findings for road traffic noise if exposure to other noise sources suggested the same as seen for road traffic noise. For railway noise, we found no suggestions of any relationship with NHL. However, due to a lower number of exposed cases compared with road traffic noise, and generally lower levels of noise exposure, we applied a lower cut-point for the highest exposure category for railway noise than for road traffic noise, which together with previous findings showing that railway noise is perceived as less annoying than road traffic noise (Miedema and Vos, 2007), might explain why we did not find any association. Regarding airport noise, there were only 17 exposed cases which did not allow detection of weak to moderate associations with NHL.

The present study suggested that road traffic noise was associated with both B-cell lymphoma and unspecified lymphoma, whereas for T-cell lymphomas no association was found. The lack

of association for T-cell lymphomas may be a result of the small numbers and chance. It is, however, in line with many other studies showing etiologic heterogeneity among subtypes of NHL (Morton et al., 2014).

The strengths of this study include its size and design. The study was a register-based approach based on the entire Danish population, using national registries of high quality with nearly complete coverage of all Danish residents. The exposure to road traffic noise covered a 5-year period before a diagnosis of NHL and based on register information on historical addresses, road lines and traffic collected from national registers and municipalities. This approach minimized the risk for selection bias and differential misclassification. The register-based nature of the study, however, restricts the available data on potential confounders. There are, however, only few established risk factors for NHL, which includes certain infections (HIV, hepatitis C and Epstein Barr), chemicals and occupations (Alexander et al., 2007; Coglianò et al., 2011). Although we did not have information on these risk factors, it seems unlikely that they would result in major confounding in the present study, as they are not common infections and exposures. A potential confounder is air pollution, which is correlated with road traffic noise and has been suggested associated with NHL (Neasham et al., 2011). However, the association are not established, and additional adjustment for air pollution resulted in only minor changes. Also, most studies on tobacco smoking have found no association with NHL (Alexander et al., 2007; Coglianò et al., 2011).

Another limitation was that we had information on exposure only five years preceding a diagnosis of NHL. However, studies of lymphoproliferative diseases after organ transplantation followed by immunosuppressive medication have observed an excess risk of lymphoma occurring already in the second or third year after transplantation, indicating that the latency period of NHL is shorter than for most other types of cancer (Faull et al., 2005), though it may be longer for conditions with less severe impairments of the immune system. Also, we found a strong correlation between 1- and 5-years' time-weighted means of road traffic noise, which suggests that the 5-year mean is also a good proxy for longer term exposure to road traffic noise. 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, e.g., we lacked information on road noise barriers and asphalt type. This may result in exposure misclassification, though conceivably non-differential. Another limitation was that we had no information on individual factors associated with the experience of noise, such as bedroom location, window opening habits or hearing impairment. Studies of traffic noise and cardiovascular diseases have found stronger associations with road traffic noise when these factors are considered (Selander et al., 2009b), indicating that an effect of noise might be underestimated in the present study. Finally, the exposure to road traffic noise during the night (L_n) was highly correlated with exposure during the day (L_d , R spearman = 0.996) and we could thus not separate the effect of the two exposures.

In conclusion, our nationwide study indicates that exposure to road traffic noise at high levels may be associated with NHL among adults. However, as the first study of traffic noise and risk for NHL, our results should be interpreted with caution.

Ethical considerations

The present study was a strictly register-based study with no contact to the study population, and, therefore, the study required no permission from an ethical committee (according to Danish legislation).

Conflicts of interests

None declared.

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