Original Article

Nighttime road traffic noise exposure at the least and most exposed façades and sleep medication prescription redemption—a Danish cohort study

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Abstract

Study Objectives: Traffic noise has been associated with poor sleep quality and short sleep duration. This study investigates the association between nighttime road traffic noise at the least and most exposed façades of the residence and redemption of sleep medication.

Methods: In a cohort of 44,438 Danes, aged 50–64 at baseline (1993–1997), we identified all addresses from 1987 to 2015 from a national registry and calculated nighttime road traffic noise at the most and least exposed façades. Using Cox Proportional Hazard Models we investigated the association between residential traffic noise over 1, 5, and 10 years before redemption of the first sleep medication prescription in the Danish National Prescription Registry. During a median follow-up time of 18.5 years, 13,114 persons redeemed a prescription.

Results: We found that 10-year average nighttime exposure to road traffic noise at the most exposed façade was associated with a hazard ratio (HR) of 1.05, 95% confidence interval (CI) (1.00 to 1.10) for L_n greater than 55 as compared to not more than 45 dB, which when stratified by sex was confined to men (HR 1.16, 95% CI 1.08 to 1.25). For the least exposed façade the HR for L_n >45 vs ≤35 dB was 1.00, 95% CI (0.95 to 1.05). For the most exposed façade, the overall association was strongest in smokers and physically inactive.

Conclusions: Long-term residential nighttime noise exposure at the most exposed façade may be associated with a higher likelihood of redeeming prescriptions for sleep medication, especially among men, smokers, and physically inactive.

Statement of Significance

The quality of the evidence for an association between traffic noise and sleep has been evaluated as very low to moderate by the WHO expert group, emphasizing the need for more prospective studies. This prospective cohort study investigated residential traffic noise at the least and most exposed façades in relation to sleep medication prescriptions, finding a positive association between 10-year average noise level at the most exposed façade, especially for men, but no association for the least exposed façade. The study contributes substantially to the evidence-base on traffic noise and sleep, given its numerous cases and its noise modeling at both the least and most exposed façade. The finding of differing associations across subgroups, however, warrants further investigation into this.

Key words: cohort study; sleep medication; prescription registry; road traffic noise; epidemiology

Introduction

According to the World Health Organization (WHO), one in five EU citizens report experiencing sleep disturbance due to nighttime traffic noise [1], and sleep disturbance is the main health impact associated with environmental noise [2]. Traffic noise has been associated with both poorer sleep quality, as well as shorter sleep duration [1, 3, 4].

Effects of transportation noise on sleep were evaluated in a recent systematic review commissioned by the WHO. The review included both objectively and subjectively measured sleep disturbance and found a significant, positive association between traffic noise (road, rail, and aircraft) and objective sleep measures using polysomnographic data, which is considered the gold standard in sleep measurement. But the authors commented that the number of studies included were few ($n = 4$) and had low generalizability, as they were primarily conducted with young and healthy participants. In the meta-analysis of subjectively measured sleep disturbance based on questionnaires, they discerned between those studies asking about sleep disturbance from a specific noise source and those not doing so. They found that when asking about a specific noise source, there was a statistically significant, positive association between transportation noise (both from aircraft and road and rail) and sleep disturbance, whereas when the noise source was not mentioned in the question, the association was still positive, but less pronounced and nonsignificant. A general limitation of the studies on subjectively measured sleep disturbance was the various wording and definition of questions as well as the definition of the outcome, which included both awakenings, difficulty falling asleep and difficulty in relation to sleep maintenance [5]. The WHO expert group evaluated the quality of the existing evidence for an association between traffic noise and the different sleep outcomes as very low to moderate [5], emphasizing the need for future studies, especially of prospective design.

This highlights the challenges in existing studies on traffic noise and sleep, as objective sleep measurement by polysomnography is expensive and time-consuming in large studies, whereas self-reported assessment of sleep quality and quantity may be affected by question wording and personal interest [6]. In order to limit such misclassification, registry-based information on the prescription of sleep medication may be used as an objective measure of sleep disturbance. Three previous studies have examined the association between traffic noise and registry-based information on sleep medication prescription redemption [7–9], with none finding an association in the main analysis, but two suggesting a positive association in subgroups defined by season and window-opening habits [7] and area-level social deprivation [8], respectively. However, two of the studies looked at sleep medication in combination with anxiolytics and antidepressants [8, 9], and thus further studies are required.

When studying residential traffic noise exposure, there is an increasing interest in the potentially compensatory effects of having access to a quiet side of the dwelling, which has been suggested to mitigate the harmful effects of the noise at the most exposed façade [10–12]. This is particularly relevant in studies on sleep outcomes, as having access to a quiet side would allow for alteration of nighttime noise exposure by placing the bedroom there, reflecting a behavioral regulation of noise exposure.

The aim of our study was to investigate the association between modeled nighttime road traffic noise at the most and least exposed façade of the residence and registry-based information on the redemption of sleep medication, in the Danish Diet, Cancer and Health cohort. Furthermore, we investigated potential effect modification of the association by sex, lifestyle factors, and cohabitation.

Methods

Study population

A detailed description of the Diet, Cancer and Health cohort has been published previously [13]. Briefly, 160,725 Danes were invited to participate from 1993 to 1997. Inclusion criteria were residence in the greater Copenhagen or Aarhus area, 50–64 years of age, and no previous cancer diagnosis in the Danish Cancer Registry. In total, 57,053 participants (29,875 women) accepted and were included in the study, representing 7% of the Danish population in this age group. The study was approved by the local ethical committees of Copenhagen and Frederiksberg Municipalities. All participants provided written informed consent, and the study was conducted according to the Helsinki Declaration.

Exposure assessment: traffic noise

Complete residential address history for all participants was collected from July 1, 1987 and until the end of the follow-up through the Danish civil registration system [14]. Road traffic noise exposure was calculated for the years 1995, 2000, 2005, 2010, and 2015, as the equivalent continuous A-weighted sound pressure level (L_{aeq}), at both the most and least exposed facades of the address during the nighttime (L_n; 10:00 pm to 07:00 am).

Using SoundPLAN (version 8.0; SoundPLAN Nord ApS), which implements the joint Nordic prediction method [15], we calculated road traffic noise exposure. This allows for the calculation of equivalent noise levels for each address, based on information on traffic and topographic parameters. Initially, a three-dimensional model was built, which included building polygons (linked with address points), roads, and terrain for each year. Input variables on traffic data, vehicle distribution, diurnal variation, traffic speeds, and noise barriers, and finally noise levels were estimated and linked to each address point and added into the model.

Information on the three-dimensional building polygons and geographic situation of all buildings in Denmark was obtained from the Agency for Data Supply and Efficiency for the year 2012. All residential addresses within these buildings were obtained from the Building and Housing Registry for the year 2017 [16]. For ground-level dwellings, the height at which the noise was estimated was set to 2 m. For all other floors, the height was calculated using the following formula: calculation height = $2 + 2.8 \times$ (number of floors – 1). Buildings with an area of less than 40 m² were excluded from the noise model. Noise levels were calculated at the center of all facades of each residential building unit, and afterward the least and most exposed facades of each residential unit were selected. In large blocks of apartments and town houses there were often several address points inside the same building polygon. To control for this, buildings with more

than two address points were divided into separate building polygons for each address point. The reflection loss for building facades was set to 1 dB, and first- and second-order reflections were accounted for.

Information on the terrain was downloaded from GeoDanmark [17] for the year 2012, and added to the model, to account for the screening effect from the terrain. Urban areas, road surfaces, and large bodies of water were assumed fully reflecting, and all other areas were considered fully absorbent. The screening effect of buildings and noise barriers around all state roads were included. Furthermore, screening effects from noise berms, terrain, and embankments were included.

All traffic information was obtained from an updated national road and traffic database [18]. This database includes all necessary road and traffic information for air quality and noise exposure calculations. The database was an extension and update of the Danish national GIS-based road network and traffic database for 1960–2005 to the years 2005–2020. The original road network has been extended with new motorway sections that have been established since the original road network from 2007. The development in traffic flow and vehicle mix has been analyzed based on traffic data from the Danish Road Directorate to estimate the trend for different road types from 1995 to 2020, as 1995 is the baseline year of the original road and traffic database.

For all road lines, the following attributes were used: road type, annual average daily traffic (AADT), vehicle distribution, and traffic speed for each of the 5-year intervals, and these were added into the model.

Roads were classified into four categories: motorways and expressways, other roads with a width greater than 6 m, roads with a width of 3–6 meters, and other residential roads. We assumed that for smaller roads with an AADT not more than 200 this had no significant contribution to the noise estimation. In the national road and traffic database, all roads with no traffic information or with traffic flow less than 200 AADT have been assigned the value 200. Information on the nighttime traffic was included based on standard diurnal traffic distributions defined in the national road and traffic database to be able to calculate hourly values for each hour during a year. Standard diurnal traffic distributions are defined for different road types (defined above), vehicle categories (passenger cars, vans, trucks, buses), and day cases (Mondays to Thursdays, Fridays, Saturdays and Sundays, and further into the holiday month of July and other months). The vehicle distribution was assessed separately for motorways and other roads as an average percentage distribution, subdivided into motorways and all other roads, and for light and heavy vehicles, respectively. Traffic speeds for each road segment are based on a combination of road type and speed limits for each road type.

Outcome assessment: redemption of sleep medication

Information on redeemed prescriptions for sleep medication was collected from the Danish National Prescription Registry, which contains data on all prescription drugs sold in Denmark since 1995 [19]. The register includes the date of dispensing as well as information on the name and type of drug prescribed according to the Anatomic Therapeutic Chemical (ATC) system [20]. However, the indication for prescribing is not available, and neither is information on prescriptions that were issued but never redeemed. We used these data to identify people who redeemed prescriptions for orally administered sleep medication (ATC: N05CC-CF, N05CH except N05CD08).

We excluded all participants who filed one or more prescriptions of the above-mentioned ATC codes before the start of follow-up (July 1, 1997) in order to include only incident cases.

Covariates

At baseline of the Diet, Cancer and Health study, all participants filled in a food frequency and a lifestyle questionnaire, and anthropometric measures were collected by trained personnel. The data on diet and lifestyle factors hail from this questionnaire [13].

Information on socioeconomic variables, for example, highest attained education, income, and marital status at baseline, was available from Statistics Denmark. Selection of covariates was done a priori, based on a review of existing literature, biological plausibility, and availability of data, as well as a Directed Acyclic Graph (DAG) (Supplementary Figure S1).

The definition of the neighborhood-level socioeconomic variables (proportion of inhabitants with low disposable income, only basic education, and unemployed at parish level) is described in detail previously [21].

Calculation of hazard ratios (HRs) for redemption of sleep medication was conducted in a stepwise process: First, with adjustment for age (by design), calendar year, and sex (Model 1) and then additionally for socioeconomic factors: educational level (basic, vocational, higher), disposable income (in quintiles), and proportion of inhabitants with low disposable income (parish level), proportion of inhabitants with only basic education (parish level), proportion of inhabitants being unemployed (parish level) (Model 2).

Lifestyle factors were identified as mediators and not confounders in the DAG. Previous studies have proposed an association between traffic noise and several lifestyle factors including obesity [22–24], alcohol intake [25], smoking [25], and physical activity [26, 27]. Hence, adjustment for these could result in overadjustment with the removal of part of the causal pathway between traffic noise exposure and sleep medication redemption. They were thus only investigated as potential effect modifiers in interaction analyses.

Finally, information on Charlson Comorbidity Index [28] 1 year before the first prescription redemption was calculated based on data from the Danish National Patient Registry [29] and investigated as a potential effect modifier.

Statistical methods

We used Cox Proportional Hazard Models to estimate HRs and 95% confidence intervals (CIs) for the association between residential nighttime road traffic noise exposure and redemption of sleep medication. Age was used as the underlying time scale to ensure comparison of individuals at the same age. We used left truncation at age on July 1, 1997 to ensure at least 10 years of exposure history for all participants and right censoring at age of prescription redemption, death, emigration, or December 31, 2015, whichever came first.

Exposure to residential nighttime road traffic noise was modeled as time-weighted averages for the preceding 1, 5, and 10 years at a given age, taking into account preceding and current addresses in the respective periods. These exposure measures were entered as time-dependent variables into the statistical model.

The assumption of linearity of road traffic noise and continuous covariates (proportion of inhabitants with low disposable income, proportion of inhabitants with only basic education, proportion of unemployed inhabitants, alcohol intake) in relation to sleep medication redemption was evaluated by graphical evaluation using linear spline models, and the exposure–response function was plotted using smoothed splines with four degrees of freedom [30]. We found that the association between nighttime road traffic noise at both the least and most exposed façade and sleep medication redemption deviated significantly from linearity, and therefore, all analyses were performed as categorical analyses. For nighttime road traffic noise at the most exposed façade, the categories were L_n ≤45 dB, >45–50 dB, >50–55 dB, and >55 dB, and for the least exposed façade they were L_n ≤35 dB, >35–40 dB, >40–45 dB, and >45 dB. These cutoffs for the most exposed façade were selected to reflect the WHO recommendation of reducing nighttime road traffic noise (L_n) to less than 45 dB [31].

Furthermore, for one covariate, the proportion of inhabitants with low disposable income, we also found a statistically significant deviation from linearity. Hence, this was included as a spline with a boundary at 0.065. The proportional hazards assumption of the Cox Models was tested by a correlation test between the scaled Schoenfeld residuals and the rank order of event time. We used the function cox.zph in the statistical software R, and the proc lifetest option in SAS. Deviation from the assumption was detected for disposable income, and thus this was included in the analyses as strata.

In order to assess potential effect modification of the association between nighttime traffic noise exposure and sleep medication redemption by sex, lifestyle factors, and cohabitation, we conducted analyses stratified into subgroups defined by each variable and examined the association between nighttime road traffic noise exposure and sleep medication redemption individually in each subgroup.

Furthermore, as a sensitivity analysis, we repeated the main analysis in a limited study population, excluding cases who had a Charlson score greater than 0 in the last year before first prescription redemption, as disease may be caused by traffic noise, and at the same time diagnosis of a severe disease could acutely affect the sleep quality.

All tests were based on the likelihood ratio test statistic. Two-sided 95% CIs were calculated based on Wald's test of the Cox regression parameter, that is, on the log-ratio scale. P-values <0.05 were considered statistically significant. The analyses were performed using the procedure PHREG in SAS, version 9.3 on a windows platform (SAS Institute Inc., Cary, NC). The graphical evaluation of the proportional hazards assumption and the linear spline models was conducted in R, version 3.5.1.

Results

Of the 57,053 participants in the Diet, Cancer and Health cohort, we excluded 574 with a cancer diagnosis before baseline, 7,792 persons who redeemed a prescription for sleep medication before baseline, 234 who emigrated or died before July 1, 1997, 1,195 persons with missing exposure data, due to lack of address history, and 2,820 with missing covariate data, leaving 44,438 persons in the final study population. Of these, 13,114 redeemed a sleep medication prescription within the study period.

Across increasing nighttime noise exposure at the most exposed façade, the proportion of females was higher, the participants were somewhat older, there was a lower proportion of persons in the highest income quintile, and fewer who had a higher education, were cohabiting, were never or former smokers, and who were physically active. In contrast, there was a higher proportion of alcohol abstainers across increasing nighttime noise exposure. For the area-level variables, there was a higher proportion of persons with low income and of unemployed across the exposure spectrum (Table 1). Across increasing nighttime exposure at the least exposed façade, there was a similar tendency of a higher proportion of females, a higher median age, and fewer with a higher education across the exposure spectrum, whereas there was no clear tendency for personal income, cohabitation, smoking status, alcohol, physical activity, and area-level variables (Supplementary Table S1). The correlation ($R_{Spearman}$) between noise at the least and most exposed façades was 0.46.

The association between 1, 5, and 10 year nighttime road traffic noise exposure at the most exposed façade and prescription redemption is provided in Table 2. There was no association with 1- and 5-year exposure, but for 10-year exposure, there was a positive tendency across exposure groups, with increasing HRs, reaching an HR (95% CI) of 1.05 (1.00 to 1.10) in the L_n >55 dB exposure group.

In Table 3 the associations between 1-, 5-, and 10-year nighttime road traffic noise exposure at the least exposed façade and prescription redemption are given. Here, we found a suggestion of an inverse association between traffic noise exposure and sleep medication prescription redemption over a 1- and 5-year period, in the highest exposure group (L_n > 45 dB) for both 1 year (HR (95% CI): 0.95 (0.90 to 1.00)) and 5 years (0.96 (0.91 to 1.01)). However, we did not see a tendency across the exposure groups.

When investigating whether sex, lifestyle factors, cohabitation, and education modified the association between nighttime road traffic noise at the most exposed façade and redemption of sleep medication, we found a positive association between noise exposure and redemption of sleep medication for men, with an exposure–response association across exposure categories, whereas for women this was not the case: For the most exposed (L_n > 55 dB) compared to the least exposed (L_n ≤ 45 dB) over a 10-year period, the HR (95% CI) for men was 1.16 (1.08 to 1.25) and for women 0.97 (0.91 to 1.04). Albeit less pronounced, the results also suggested stronger positive associations and an exposure–response association between noise exposure and prescription redemption among ever vs never smokers and nonparticipants in sports compared to physically active and to some degree also for those living alone compared to those cohabiting (Table 4). In analyses of the least exposed façade, there were similar tendencies for sex and physical activity, albeit much less pronounced. There were also indications of a direct effect among those drinking alcohol below the recommendations, however, with no clear pattern of an exposure–response association (Table 5).

Table 1. Baseline characteristics of the Diet, Cancer and Health cohort according to road traffic noise exposure at the most exposed façade at baseline*

	Total cohort	L_n ≤45 dB	L_n >45 to ≤50 dB	L_n >50 to ≤55 dB	L_n >55 dB
	N = 44,438	N = 15,406	N = 11,116	N = 9,552	N = 8,364
Nighttime road traffic noise, most exposed façade, dB	48.0 (36.0–61.1)	41.2 (32.7–44.7)	47.4 (45.3–49.8)	52.2 (50.3–54.7)	58.6 (55.3–65.5)
Nighttime road traffic noise, least exposed façade, dB	39.8 (30.4–50.1)	36.4 (28.2–42.6)	42.8 (32.7–47.6)	43.0 (32.5–51.0)	41.9 (32.8–54.4)
Female, %	50.7	49.1	50.8	51.9	52.0
Age at baseline, years	57.3 (51.7–65.5)	57.1 (51.5–65.4)	57.3 (51.7–65.3)	57.6 (51.8–65.6)	57.6 (52.0–65.8)
Follow-up time, years	18.5 (1.7–18.5)	18.5 (1.8–18.5)	18.5 (1.8–18.5)	18.5 (1.7–18.5)	18.5 (1.6–18.5)
Household income, %					
First quintile	4.0	2.8	3.5	4.9	6.2
Second quintile	10.5	7.9	9.7	12.3	14.1
Third quintile	13.0	11.3	12.8	13.9	15.4
Fourth quintile	22.1	20.9	21.9	22.6	23.8
Fifth quintile	50.4	57.2	52.1	46.3	40.4
Education, %					
Basic	27.2	24.4	26.6	29.4	30.6
Vocational	46.1	45.4	46.6	45.7	47.5
Higher	26.7	30.3	26.8	24.9	22.0
Cohabiting, %	73.0	78.9	73.9	68.6	66.0
Area-level† percentage of:					
Persons with low income, %	9 (4–25)	8 (4–21)	9 (4–23)	10 (4–29)	11 (3–29)
Persons with basic education, %	24 (12–38)	24 (11–35)	26 (12–38)	25 (13–38)	24 (12–38)
Persons unemployed, %	6 (4–11)	5 (3–9)	6 (4–11)	6 (4–12)	7 (4–13)
Smoking status, %					
Never	36.6	38.5	38.1	35.1	32.9
Former	28.1	29.5	27.5	27.5	27.0
Current	35.3	32.0	34.3	37.4	40.1
Alcohol, g/day‡	13.3 (1.2–64.0)	13.3 (1.2–61.2)	13.5 (1.2–63.3)	13.0 (1.0–65.2)	13.5 (1.0–68.5)
Abstainers, %	2.0	1.6	2.1	2.2	2.3
Leisure-time physical activity	54.4	57.1	55.6	52.7	49.5

*Median and 5–95 percentile, unless otherwise stated.
†By parish.
‡Among those drinking alcohol.

Table 2. Crude and adjusted associations between nighttime residential road traffic noise exposure (L_n) at the most exposed façade and sleep medication prescription redemption

	Cases	Model 1* HR (95% CI)	Model 2† HR (95% CI)
Average L_n 1 year before prescription redemption			
≤45 dB	3,532	1.00 (ref.)	1.00 (ref.)
>45 to ≤50 dB	3,516	1.00 (0.95 to 1.04)	1.00 (0.95 to 1.05)
>50 to ≤55 dB	3,402	1.02 (0.98 to 1.07)	1.03 (0.98 to 1.08)
>55 dB	2,664	1.01 (0.96 to 1.06)	1.01 (0.96 to 1.06)
Average L_n 5 years before prescription redemption			
≤45 dB	3,413	1.00 (ref.)	1.00 (ref.)
>45 to ≤50 dB	3,531	1.00 (0.95 to 1.04)	1.00 (0.95 to 1.05)
>50 to ≤55 dB	3,478	1.02 (0.98 to 1.07)	1.03 (0.98 to 1.08)
>55 dB	2,692	1.01 (0.96 to 1.06)	1.01 (0.96 to 1.06)
Average L_n 10 years before prescription redemption			
≤45 dB	3,270	1.00 (ref.)	1.00 (ref.)
>45 to ≤50 dB	3,583	1.02 (0.97 to 1.07)	1.02 (0.98 to 1.07)
>50 to ≤55 dB	3,536	1.03 (0.98 to 1.08)	1.03 (0.99 to 1.08)
>55 dB	2,725	1.05 (1.00 to 1.10)	1.05 (1.00 to 1.10)

*Adjusted for age (by design), calendar year, and sex.
†Adjusted as Model 1, and additionally for educational level (basic, vocational, higher), disposable income (in quintiles), cohabitation status (married/registered partnership, and other), proportion of inhabitants with low disposable income (parish level), proportion of inhabitants with only basic education (parish level), proportion of inhabitants being unemployed (parish level).

Table 3. Crude and adjusted associations between nighttime residential road traffic noise exposure (L_n) at the least exposed façade and sleep medication prescription redemption

	Cases	Model 1* HR (95% CI)	Model 2† HR (95% CI)
Average L_n 1 year before prescription redemption			
≤35 dB	2,362	1.00 (ref.)	1.00 (ref.)
>35 to ≤40 dB	3,847	1.00 (0.96 to 1.05)	1.00 (0.96 to 1.05)
>40 to ≤45 dB	3,829	1.00 (0.95 to 1.04)	1.01 (0.96 to 1.06)
>45 dB	3,062	0.93 (0.89 to 0.98)	0.95 (0.90 to 1.00)
Average L_n 5 years before prescription redemption			
≤35 dB	2,220	1.00 (ref.)	1.00 (ref.)
>35 to ≤40 dB	3,948	1.02 (0.98 to 1.08)	1.02 (0.97 to 1.07)
>40 to ≤45 dB	3,949	1.02 (0.97 to 1.07)	1.03 (0.98 to 1.09)
>45 dB	2,997	0.94 (0.90 to 0.99)	0.96 (0.91 to 1.01)
Average L_n 10 years before prescription redemption			
≤35 dB	2,077	1.00 (ref.)	1.00 (ref.)
>35 to ≤40 dB	4,048	1.01 (0.97 to 1.07)	1.01 (0.96 to 1.06)
>40 to ≤45 dB	4,052	1.00 (0.95 to 1.05)	1.01 (0.96 to 1.07)
>45 dB	2,937	0.98 (0.93 to 1.03)	1.00 (0.95 to 1.05)

*Adjusted for age (by design), calendar year, and sex.
†Adjusted as Model 1, and additionally for educational level (basic, vocational, higher), disposable income (in quintiles), cohabitation status (married/registered partnership, and other), proportion of inhabitants with low disposable income (parish level), proportion of inhabitants with only basic education (parish level), and proportion of inhabitants being unemployed (parish level).

Table 4. Modification of the association between nighttime road traffic noise at the most exposed façade (L_n) by sex, lifestyle factors, cohabitation, and education

		Average L_n 1 year before prescription redemption	Average L_n 5 years before prescription redemption	Average L_n 10 years before prescription redemption		Average L_n 1 year before prescription redemption	Average L_n 5 years before prescription redemption	Average L_n 10 years before prescription redemption
	N cases	HR (95% CI)*	HR (95% CI)*	HR (95% CI)*	N cases	HR (95% CI)*	HR (95% CI)*	HR (95% CI)*
Sex	Male				Female			
≤45 dB	1,456	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1,814	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)
>45 to ≤50 dB	1,512	1.01 (0.94 to 1.09)	1.04 (0.97 to 1.11)	1.05 (0.98 to 1.13)	2,071	0.99 (0.93 to 1.05)	0.99 (0.93 to 1.05)	1.00 (0.94 to 1.06)
>50 to ≤55 dB	1,457	1.06 (0.98 to 1.13)	1.05 (0.97 to 1.12)	1.07 (0.99 to 1.15)	2,079	1.00 (0.94 to 1.08)	1.01 (0.95 to 1.07)	1.01 (0.95 to 1.07)
>55 dB	1,188	1.08 (1.00 to 1.16)	1.11 (1.03 to 1.20)	1.16 (1.08 to 1.25)	1,537	0.96 (0.90 to 1.02)	0.95 (0.89 to 1.01)	0.97 (0.91 to 1.04)
Obese†	Yes				No			
≤45 dB	429	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	2,840	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)
>45 to ≤50 dB	493	0.99 (0.87 to 1.11)	1.01 (0.90 to 1.15)	1.02 (0.92 to 1.18)	3,083	1.00 (0.95 to 1.05)	1.01 (0.96 to 1.06)	1.02 (0.97 to 1.07)
>50 to ≤55 dB	552	1.07 (0.95 to 1.21)	1.07 (0.95 to 1.20)	1.06 (0.94 to 1.20)	2,978	1.02 (0.97 to 1.07)	1.02 (0.97 to 1.07)	1.03 (0.98 to 1.08)
>55 dB	432	1.01 (0.89 to 1.15)	1.02 (0.89 to 1.16)	1.02 (0.90 to 1.16)	2,289	1.00 (0.95 to 1.06)	1.01 (0.96 to 1.07)	1.06 (1.00 to 1.11)
Smoking	Ever				Never			
≤45 dB	3,438	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1,205	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)
>45 to ≤50 dB	2,311	1.02 (0.96 to 1.08)	1.03 (0.97 to 1.09)	1.03 (0.97 to 1.09)	1,272	0.97 (0.90 to 1.05)	0.98 (0.91 to 1.06)	1.01 (0.94 to 1.09)
>50 to ≤55 dB	2,404	1.05 (0.99 to 1.11)	1.05 (1.00 to 1.12)	1.07 (1.01 to 1.14)	1,132	0.98 (0.91 to 1.06)	0.97 (0.89 to 1.05)	0.95 (0.88 to 1.03)
>55 dB	1,920	1.03 (0.97 to 1.09)	1.04 (0.98 to 1.11)	1.08 (1.02 to 1.15)	805	0.96 (0.88 to 1.04)	0.95 (0.87 to 1.04)	0.98 (0.89 to 1.07)
Alcohol	>recommendations				≤recommendations‡			
≤45 dB	1,403	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1,205	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)
>45 to ≤50 dB	1,507	0.96 (0.89 to 1.03)	0.95 (0.89 to 1.02)	0.98 (0.91 to 1.05)	2,076	1.03 (0.97 to 1.09)	1.05 (0.99 to 1.11)	1.05 (0.99 to 1.12)
>50 to ≤55 dB	1,477	1.02 (0.95 to 1.09)	1.01 (0.94 to 1.08)	1.03 (0.95 to 1.10)	2,059	1.03 (0.97 to 1.10)	1.04 (0.98 to 1.10)	1.04 (0.98 to 1.11)
>55 dB	1,204	0.97 (0.90 to 1.04)	0.99 (0.92 to 1.07)	1.03 (0.95 to 1.11)	1,521	1.03 (0.97 to 1.10)	1.03 (0.96 to 1.10)	1.06 (0.99 to 1.13)
Leisure-time sports	No				Yes			
≤45 dB	1,350	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1,920	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)
>45 to ≤50 dB	1,583	1.07 (1.00 to 1.15)	1.10 (1.02 to 1.17)	1.13 (1.05 to 1.21)	2,000	0.95 (0.89 to 1.01)	0.95 (0.89 to 1.01)	0.95 (0.89 to 1.01)
>50 to ≤55 dB	1,644	1.04 (0.97 to 1.12)	1.04 (0.97 to 1.12)	1.05 (0.98 to 1.13)	1,892	1.01 (0.95 to 1.08)	1.01 (0.95 to 1.08)	1.02 (0.96 to 1.09)
>55 dB	1,384	1.07 (1.00 to 1.15)	1.08 (1.01 to 1.17)	1.12 (1.04 to 1.20)	1,341	0.95 (0.89 to 1.02)	0.96 (0.89 to 1.02)	0.99 (0.93 to 1.07)
Cohabiting	No				Yes			
≤45 dB	632	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	2,638	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)
>45 to ≤50 dB	953	1.00 (0.91 to 1.09)	0.99 (0.91 to 1.09)	1.07 (0.98 to 1.18)	2,630	1.00 (0.95 to 1.06)	1.02 (0.96 to 1.07)	1.01 (0.96 to 1.06)
>50 to ≤55 dB	1,146	1.06 (0.97 to 1.15)	1.07 (0.98 to 1.17)	1.12 (1.02 to 1.22)	2,390	1.01 (0.96 to 1.07)	1.01 (0.96 to 1.05)	1.01 (0.95 to 1.06)
>55 dB	982	1.01 (0.92 to 1.11)	1.01 (0.92 to 1.11)	1.07 (0.98 to 1.18)	1,743	1.01 (0.95 to 1.07)	1.02 (0.96 to 1.08)	1.05 (0.99 to 1.11)
Education	Low				Medium/high			
≤45 dB	804	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	2,465	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)
>45 to ≤50 dB	1,001	1.00 (0.91 to 1.09)	1.04 (0.95 to 1.13)	1.04 (0.95 to 1.14)	2,575	1.00 (0.95 to 1.05)	1.00 (0.95 to 1.06)	1.02 (0.96 to 1.07)
>50 to ≤55 dB	1,074	1.04 (0.95 to 1.13)	1.03 (0.94 to 1.12)	1.02 (0.93 to 1.11)	2,456	1.02 (0.97 to 1.08)	1.02 (0.97 to 1.08)	1.04 (0.99 to 1.10)
>55 dB	869	1.07 (0.97 to 1.17)	1.06 (0.96 to 1.16)	1.08 (0.98 to 1.18)	1,852	0.98 (0.92 to 1.04)	1.00 (0.94 to 1.06)	1.04 (0.98 to 1.10)

*Adjusted for age (by design), calendar year, sex, proportion of inhabitants with low disposable income (parish level), proportion of inhabitants with only basic education (parish level), proportion of inhabitants being unemployed (parish level), educational level (basic, vocational, higher), disposable income (in quintiles), cohabitation status (married/registered partnership, and other).

†BMI ≥30 kg/m².

‡The Danish Health Authority recommends no more than 7 units (in Denmark defined as 12 g alcohol) per week for women and 14 units for men.

When examining exposure at the least and most exposed façades in combination, we found no tendency toward a combined effect of the exposure at the two facades and sleep medication prescription redemption (Supplementary Table S2).

As a sensitivity analysis, we excluded cases with comorbidities, defined as a Charlson score greater than 0 (*n* = 3,124). For both facades, the HRs then suggested no association (Supplementary Table S3).

Finally, all analyses were also calculated for road traffic noise exposure over the entire day (L_{den}), yielding very similar HRs to the findings for L_n, due to the very high correlation ($R_{Spearman}$ 0.999 for both least and most exposed facade) between these two measures (results not shown).

Discussion

In the present study, we found suggestions of a positive association between 10-year nighttime traffic noise exposure at the most exposed façade and redemption of sleep medication prescriptions, which in sex-stratified analyses were confined to men. We also found indications of stronger positive associations and a tendency across exposure groups among ever smokers and nonparticipants in leisure-time sports, compared to never smokers and those engaging in leisure-time sports. In contrast, nighttime exposure at the least exposed façade seemed inversely associated with sleep medication prescription redemption in 1- and 5-year exposure windows, however, only in the highest exposure category, and with no clear tendency across

Table 5. Modification of the association between nighttime road traffic noise at the least exposed façade (L_n) by sex, lifestyle factors, cohabitation, and education

		Average L_n 1 year before prescription redemption	Average L_n 5 years before prescription redemption	Average L_n 10 years before prescription redemption		Average L_n 1 year before prescription redemption	Average L_n 5 years before prescription redemption	Average L_n 10 years before prescription redemption
	N cases	HR (95% CI)*	HR (95% CI)*	HR (95% CI)*	N cases	HR (95% CI)*	HR (95% CI)*	HR (95% CI)*
Sex	Male				Female			
≤35 dB	924	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1,153	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)
>35 to ≤40 dB	1,811	1.06 (0.98 to 1.14)	1.07 (0.99 to 1.15)	1.08 (1.00 to 1.16)	2,237	0.96 (0.90 to 1.02)	0.99 (0.93 to 1.06)	0.96 (0.90 to 1.03)
>40 to ≤45 dB	1,666	1.02 (0.94 to 1.09)	1.03 (0.95 to 1.11)	1.03 (0.95 to 1.11)	2,386	1.00 (0.93 to 1.06)	1.03 (0.96 to 1.10)	1.00 (0.94 to 1.07)
>45 dB	1,212	1.00 (0.92 to 1.08)	1.01 (0.93 to 1.09)	1.05 (0.97 to 1.14)	1,725	0.92 (0.86 to 0.99)	0.93 (0.86 to 0.99)	0.96 (0.90 to 1.03)
Obese†	Yes				No			
≤35 dB	282	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1,795	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)
>35 to ≤40 dB	558	0.99 (0.97 to 1.12)	1.08 (0.94 to 1.23)	1.06 (0.92 to 1.21)	3,487	1.00 (0.95 to 1.06)	1.01 (0.96 to 1.07)	1.01 (0.95 to 1.06)
>40 to ≤45 dB	593	1.01 (0.89 to 1.15)	1.09 (0.96 to 1.25)	1.05 (0.92 to 1.21)	3,450	1.00 (0.95 to 1.06)	1.02 (0.97 to 1.08)	1.01 (0.95 to 1.06)
>45 dB	473	0.98 (0.86 to 1.12)	1.04 (0.95 to 1.19)	1.04 (0.91 to 1.20)	2,458	0.94 (0.89 to 1.00)	0.95 (0.90 to 1.00)	0.99 (0.93 to 1.05)
Smoking	Ever				Never			
≤35 dB	1,366	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	711	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)
>35 to ≤40 dB	2,747	1.00 (0.94 to 1.05)	1.02 (0.96 to 1.08)	1.02 (0.96 to 1.08)	1,301	1.02 (0.93 to 1.10)	1.02 (0.94 to 1.11)	1.00 (0.91 to 1.09)
>40 to ≤45 dB	2,630	1.00 (0.95 to 1.07)	1.04 (0.98 to 1.10)	1.02 (0.96 to 1.08)	1,422	1.03 (0.94 to 1.11)	1.04 (0.95 to 1.13)	1.02 (0.94 to 1.11)
>45 dB	1,957	0.97 (0.91 to 1.03)	0.98 (0.92 to 1.04)	1.01 (0.95 to 1.08)	980	0.93 (0.85 to 1.02)	0.94 (0.85 to 1.02)	0.97 (0.89 to 1.06)
Alcohol	>recommendations				≤recommendations‡			
≤35 dB	906	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1,171	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)
>35 to ≤40 dB	1,726	0.98 (0.91 to 1.05)	1.00 (0.93 to 1.08)	1.01 (0.94 to 1.09)	2,322	1.02 (0.96 to 1.08)	1.04 (0.98 to 1.11)	1.01 (0.95 to 1.08)
>40 to ≤45 dB	1,719	0.90 (0.84 to 0.97)	0.93 (0.86 to 1.00)	0.95 (0.81 to 0.99)	2,333	1.08 (1.01 to 1.15)	1.11 (1.04 to 1.18)	1.08 (1.01 to 1.16)
>45 dB	1,240	0.91 (0.84 to 0.99)	0.91 (0.84 to 0.98)	0.96 (0.88 to 1.03)	1,697	0.97 (0.90 to 1.04)	0.99 (0.92 to 1.06)	1.02 (0.95 to 1.09)
Leisure-time sports	No				Yes			
≤35 dB	902	1.00	1.00 (ref.)	1.00 (ref.)	1,175	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)
>35 to ≤40 dB	1,856	1.01 (0.94 to 1.08)	1.04 (0.97 to 1.12)	1.03 (0.96 to 1.11)	2,192	1.00 (0.94 to 1.07)	1.01 (0.95 to 1.08)	1.00 (0.94 to 1.07)
>40 to ≤45 dB	1,836	1.06 (0.99 to 1.14)	1.09 (1.02 to 1.18)	1.06 (0.98 to 1.14)	2,216	0.96 (0.90 to 1.03)	0.99 (0.92 to 1.05)	0.98 (0.91 to 1.05)
>45 dB	1,367	1.01 (0.94 to 1.10)	1.03 (0.95 to 1.11)	1.06 (0.98 to 1.14)	1,570	0.90 (0.84 to 0.97)	0.91 (0.85 to 0.98)	0.96 (0.89 to 1.07)
Cohabiting	No				Yes			
≤35 dB	486	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1,591	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)
>35 to ≤40 dB	1,138	0.97 (0.88 to 1.06)	1.03 (0.94 to 1.13)	1.00 (0.90 to 1.10)	2,910	1.02 (0.96 to 1.07)	1.02 (0.97 to 1.08)	1.02 (0.96 to 1.08)
>40 to ≤45 dB	1,183	0.98 (0.89 to 1.07)	1.01 (0.92 to 1.12)	1.02 (0.92 to 1.12)	2,869	1.02 (0.96 to 1.08)	1.04 (0.98 to 1.10)	1.01 (0.96 to 1.07)
>45 dB	906	0.95 (0.86 to 1.05)	0.98 (0.88 to 1.08)	1.01 (0.91 to 1.12)	2,031	0.95 (0.89 to 1.01)	0.96 (0.91 to 1.02)	0.99 (0.93 to 1.07)
Education	Low				Medium/high			
≤35 dB	579	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1,498	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)
>35 to ≤40 dB	1,089	1.02 (0.93 to 1.11)	1.04 (0.95 to 1.14)	1.02 (0.93 to 1.12)	2,956	1.00 (0.94 to 1.05)	1.02 (0.96 to 1.08)	1.01 (0.95 to 1.07)
>40 to ≤45 dB	1,170	1.03 (0.93 to 1.12)	1.05 (0.96 to 1.15)	1.05 (0.95 to 1.15)	2,873	1.00 (0.94 to 1.06)	1.03 (0.97 to 1.09)	1.00 (0.94 to 1.06)
>45 dB	910	1.00 (0.91 to 1.10)	1.00 (0.91 to 1.10)	1.02 (0.92 to 1.12)	2,021	0.93 (0.88 to 0.99)	0.94 (0.89 to 1.01)	0.99 (0.93 to 1.05)

*Adjusted for age (by design), calendar year, sex, proportion of inhabitants with low disposable income (parish level), proportion of inhabitants with only basic education (parish level), proportion of inhabitants being unemployed (parish level), educational level (basic, vocational, higher), disposable income (in quintiles), cohabitation status (married/registered partnership, and other).

†BMI ≥30 kg/m².

‡The Danish Health Authority recommends no more than 7 units (defined as 12 g alcohol) per week for women and 14 units for men.

the lower exposure groups. Combinations of exposure at the least and most exposed façades did not produce a clear picture of joint effects, and exclusion of those with comorbidities the last year before redemption provided HRs close to 1.00.

The strengths of the study include the large cohort size, long follow-up time, and a high number of cases. Furthermore, the Danish National Prescription Registry, from which the outcome data hails, is well-validated and considered both complete and of high quality, and sleep medications drugs are only available on prescription in Denmark [32, 33]. However, as the registry only runs from 1995, exclusion of persons with redemption of the included ATC codes before the study start (July 1, 1997) in

order to include incident cases only, may not be complete. We were able to follow up all participants through validated Danish registries on vital status and had access to detailed address history over the entire study period, which allowed calculation of average exposure over different time windows. The modeling of exposure over time is an important study strength, as few studies have previously investigated the association in detail. The Nordic Prediction Model, which was used to calculate exposure, has been the standard method for the estimation of traffic noise in the Nordic countries for many years [15]. A validation of the model, based on a number of measurements up to 300 m from the road, found the average difference between

measurements and calculations to be 0.2 dB (noise from road traffic is typically within the range of 40–80 dB), showing that the model is very accurate [15, 34].

The study limitations include the reliance on registry-based information on sleep medication prescription redemption, which prevents direct investigation of nonclinical sleep disturbance. Our study only captures more severe and persistent sleep problems, where people both contact their physician and qualify for a prescription. The proportion of sleep medication prescription redeemers in the present cohort was 29.5% over a median follow-up period of 18.5 years. In a National Danish health survey including 175,000 Danes, 46% reported having experienced sleep problems within the last 2 weeks [35], suggesting that we do indeed fail to capture the entire spectrum of sleep disturbances. Our findings should thus not be generalized to nonclinical sleep disturbances as a result of traffic noise, as the outcome sensitivity is reduced and information on nonclinical sleep disturbance and unredeemed prescriptions is lacking. Also, the study population is not representative of the general Danish population: Participants were selected from the two major metropolitan areas of Denmark and are thus not representative of the entire Danish population with regard to residential noise exposure. Furthermore, only 35% of the invited participants accepted, with participants having a higher socioeconomic position compared to nonparticipants [13], which may limit the generalizability of our findings. Finally, the population was aged 50–64 years at inclusion [13], and given the long follow-up, they were middle-aged or old when the study ended. It is generally acknowledged that sleep structure changes with age and becomes increasingly fragmented, with more awakenings and more time spend in the lighter sleep stages [36–39], suggesting that traffic noise could be more disturbing in our study population than among a younger population. Finally, even though we were able to calculate noise exposure at both the least and most exposed facades, we did not have information on the orientation of each individual's bedroom, as well as window-opening habits.

Few other studies have previously examined the association between road traffic noise and registry-based sleep medication prescription redemption. A Finnish study found no association [9]. A Norwegian study found a borderline significant positive association, but only in the summer season and among those reporting sleeping with the windows open [7]. Unfortunately, information on window-opening habits was not available in our study, but when investigating an association between seasonal traffic noise exposure and the association with redeeming sleep medication in the summer season (June–August), we found no clear association (Supplementary Table S4). However, our study generally proposed a direct association only with the 10-year exposure measure, suggesting that seasonal variation may not necessarily play a large role in the present cohort. A French study found a positive association between road traffic noise and medication prescriptions only among those living in areas with low social deprivation [8]. Similar effect modification was not seen in our study in relation to the available area-level variables: proportion of unemployed, proportion with basic education only, and proportion with low income (Supplementary Table S5). While these three studies also used prescription data, the Finnish and French studies [8, 9] did not specifically investigate the use of hypnotics, but included also anxiolytics and/or antidepressants, which hampers comparison with our

study. Furthermore, three European studies on road traffic noise and self-reported information on sleep medication use have been conducted; none of which found an association [40–42]. Registry-based information on medication redemption is generally assessed as more valid than self-reported information on sleep disturbance or sleep medication use, which may be more prone to information bias. A Norwegian study suggested moderate agreement between self-reported and registry-based use of sleep medication [43]. Using registry-based information on sleep medication prescription redemption, rather than self-reported information on sleep disturbances, may result in a stricter outcome definition, which only includes the more severe, doctor-diagnosed, and long-lasting cases, rather than more transient sleep problems [44]. One cohort had information on both registry-based redemption and self-reported sleep medication use [7, 40], and interestingly they found an association between road traffic noise and redemption of registry-based prescriptions whereas no association was observed for self-reported use of sleep medication. One explanation of this seemingly contradictory finding could be that the self-reported data were hampered by information bias. But the two findings are not necessarily contradictory: Registry-based data on prescriptions could reflect the more severe cases, as a prescription redemption requires a visit to and an ordination from a medical doctor [7], whereas the study on self-reported sleep medication use [40] did not specify any type of medication, and this category could therefore also include nonprescription compounds and may thus represent milder cases of sleep disturbance. Interestingly, the study on self-reported sleep medication use also enquired about *difficulties falling asleep*, *awakenings during night*, and *waking up too early* and found a positive association between road traffic noise and all of these [40].

Our study found a direct association between nighttime road traffic noise at the most exposed façade and sleep medication prescription redemption with 10-year exposure only. Intuitively, traffic noise may be expected to affect sleep more acutely. But as described above, the use of registry-based information on prescription redemption as an outcome captures only clinical sleep disturbance, and in relation to this, it seems probable that a substantial amount of time is required before the sleep disturbance becomes clinical and results in redemption of a prescription for sleep medication. This should also be seen in the light of the fact that the Danish general practitioners have become more restrictive in dispensing prescriptions for sleep medication over the last decades [45, 46].

Our analyses suggested that some subgroups of the population may be more susceptible to traffic noise exposure. Most notably, there was a strong positive association between noise exposure and sleep medication prescription redemption for men. It is generally acknowledged that women report more sleep disruption and poorer sleep quality than men [35, 47] and that they are more prone to using sleep medication [48–50]. Explanations for this difference include hormonal factors and a higher female susceptibility to psychosocial factors in relation to sleep disturbance/disorders [47, 51]. Hence, it seems plausible that female sleep medication use to a higher degree is a result of internal factors, and thus unrelated to traffic noise, whereas for men, external factors, including traffic noise exposure, may to a higher degree determine sleep medication use. Similarly, a positive association between traffic noise and prescription redemption was also strongest among some already high-risk subgroups of the population: smokers and

nonparticipants in leisure-time sports. Smoking and physical inactivity have both been found independent risk factors for disturbed sleep [52, 53], suggesting that these groups could be more disturbed by traffic noise. However, we would then expect to see a similar effect also among, for example, obese and those with a high intake of alcohol, as these are also established risk factors for disturbed sleep [54, 55], which we did not clearly see.

It has been hypothesized that the presence of a quiet façade could compensate for the harmful effects of noise levels at the most exposed façade [10]. Few studies have previously included noise exposure at both the least and most exposed façade, as well as information on bedroom location. We identified two smaller studies on sleep disturbance in adults [10, 11]. Both found that having a bedroom facing a quiet side was associated with a lower risk of reporting sleep disturbance, but as information on noise exposure was self-reported through questionnaires, they could be affected by exposure misclassification. A recent, larger study in Switzerland, using modeled traffic noise, found a direct association between nighttime noise level and the probability of reporting being highly disturbed by noise, with strong effect modification by bedroom orientation, so that those with a bedroom facing the quiet side were less disturbed [12].

In our study, we found suggestions that increasing exposure at the least exposed facade seemed to entail a lower sleep medication prescription redemption in the highest exposure group. We have no a priori hypotheses for finding such an association and it may seem counterintuitive. However, if we expect people to generally place their bedroom at the least exposed façade, one could speculate that at low noise levels people will sleep with open windows, whereas at higher noise levels they will sleep with closed windows. A closed window may attenuate the indoor noise level with as much as 28 dB [56], which could entail the lowest indoor noise level at the highest outdoor exposure. Also, a recent Swiss study investigating modeled road traffic noise at both the most and least exposed facades in relation to mortality from myocardial infarction found that while road traffic noise at the most exposed façade was associated with the outcome, road traffic noise at the least exposed façade attenuated the association measure, rendering the association nonsignificant. Interestingly, the study found this attenuation only in urban areas [57]. The participants of the present study were chosen from the two major metropolitan areas in Denmark: Aarhus and Copenhagen. The authors of the Swiss study suggest that one would expect most people to have their bedroom at the least exposed façade and thus find a stronger association with exposure here compared to the most exposed façade, but the fact that they find the opposite in the urban areas could be explained by more complex traffic noise exposure pictures in urban areas with more dense building configurations and road networks resulting in complex reflection patterns, which may not be adequately accounted for in the model. Furthermore, they also proposed that the masking effects of other noise sources are stronger in urban settings and may, especially at the least exposed façade, introduce additional exposure misclassification [57]. This may also be potential explanations for the lower exposure measures between nighttime road traffic noise exposure at the least exposed façade and sleep medication in the present study. In a nationwide Danish modeling of road traffic noise exposure, the largest difference between the least and most exposed facades of buildings was found for multistory buildings, which in Denmark often have closed courtyards with little traffic noise [58], but

potentially are highly exposed to other noise sources such as neighbors and recreational areas in the closed courtyards, etc. Finally, the suggestion of an inverse association between traffic noise at the least exposed facade and sleep medication prescription redemption may also be explained by a selection of noise-sensitive persons out of dwellings with relatively high exposure at the least exposed façade, where the bedroom is normally placed. This is, however, speculative and cannot be examined using data from the present study.

In a sensitivity analysis, we excluded cases diagnosed with a serious illness within the last year before prescription redemption (Charlson score >0), as this may acutely affect sleep and entail a sleep medication prescription redemption, while at the same time a number of illnesses in the Charlson Index has been proposed associated with road traffic noise [59–63]. The fact that the sensitivity analysis finds no association in healthy individuals could suggest that our main findings may be affected by residual confounding by an underlying disease. However, it also supplements our findings of an association between traffic noise and prescription redemption in already challenged subpopulations of smokers and physically inactive, by suggesting that also populations challenged by already existing disease could have their sleep more affected by nighttime traffic. This study aspect thus requires further investigation.

In conclusion, the results of the present study suggest that long-term residential exposure to nighttime road traffic noise at the most exposed façade may increase the risk of redeeming sleep medication, primarily among men, whereas for the least exposed façade, there were suggestions of an inverse association, however, with no clear trends across exposure groups. For noise at the most exposed façade, the association seemed strongest among already high-risk subpopulations of smokers and physically inactive. The present study contributes to the relatively limited literature on traffic noise and sleep medication prescription redemption, indicating that long-term traffic noise exposure at the most exposed façade could be associated with more severe sleep disturbances, especially in men and high-risk populations. However, further studies are required, especially with regard to potentially differing associations in subgroups of the population.

Supplementary Material

Supplementary material is available at *SLEEP* online.

Acknowledgments

Disclosure Statement

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