Residential traffic noise exposure and leisure-time sports – a population-based study

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ABSTRACT

Traffic levels are significant environmental predictors for physical inactivity. We investigated associations between residential traffic noise and leisure-time sports. In a Danish cohort, we performed cross-sectional analyses using baseline questionnaire data (1993-97), and longitudinal analyses of change between baseline and follow-up (2000-02) in relation to participation status (yes/no), and MET hrs/week. Traffic noise was modelled based on address history from 1987-2002, available from national registries. Analyses were performed using logistic and linear regression. Traffic noise 5 years before baseline was associated with higher probability of non-participation in leisure-time sports; significantly for road traffic noise: OR 1.10 (1.07-1.13) and borderline for railway noise: OR 1.03 (0.99-1.07), per 10 dB. In longitudinal analyses, a 10 dB higher road traffic noise was associated with a higher probability of ceasing and a lower probability of initiating sports. Railway noise was negatively associated with baseline MET hrs/week, whereas no association was found in longitudinal analyses, or for road traffic noise. In conclusion, long-term exposure to residential road traffic noise, and to some degree railway noise, is negatively associated with physical activity.

BACKGROUND

Physical inactivity is a threat to public health. It has been estimated to cause 6-10 % of the burden of disease from cardiovascular disease, diabetes, breast and colorectal cancer, and account for 9 % of worldwide premature mortality [1]. Behavioral research and interventions towards physical inactivity have traditionally focused on individual factors, but with disappointing long-term results [2]. In the last decades, focus has increasingly turned towards multilevel ecological models, suggesting that factors of the built environment also affect individual physical activity levels [2, 3]. Several studies have found traffic levels to be a significant environmental predictor for physical inactivity in both children and adults, which has often been explained as a traffic safety issue [4-7]. However, a recent study found traffic noise annoyance associated with subsequent lower levels of physical activity in Swiss adults [8], suggesting a new mode of operation for traffic to affect physical activity.

Apart from a direct pathway between traffic noise and physical inactivity, in which traffic noise renders the outdoor environment unappealing as a venue for physical activity, it could also affect physical activity levels through an indirect pathway by means of sleep deprivation. Traffic noise has consistently been found associated with poor sleep quality and shorter sleep duration [9-11], and sleep disturbances have been found to negatively affect the capacity for physical activity, impair recovery, and increase the risk of exercise-induced injuries [12]. Another indirect pathway through which traffic noise could affect physical activity is, that it is a known systemic stressor, which has been found associated with both emotional and physiological stress [13]. A review of the association between stress and physical activity found that physiological stress generally predicted less physical activity and more sedentary behavior, albeit with some heterogeneity [14].

In recent years, exposure to traffic noise has been associated with higher risk of a number of illnesses, including cardiovascular disease [15, 16], diabetes [17], and breast cancer [18]. The pathways explaining these associations are still not clearly elucidated, but given the role of physical inactivity in the etiology of all these diseases [1], it could be speculated that part of the explanation is that traffic noise functions through a pathway of physical inactivity.

The aim of the present study was to investigate the association between residential traffic noise exposure and leisure-time physical activity, both cross-sectionally and longitudinally.

METHODS AND MATERIAL

Study population

The study is conducted in the Danish Diet, Cancer and Health cohort, which has been described in detail previously [19]. Briefly, 160,725 persons were invited to participate from 1993-97. Inclusion criteria were 50-64 years of age, residence in the greater Copenhagen area or Aarhus area and no previous cancer diagnosis in the Danish Cancer Registry. In total, 57,053 participants accepted the invitation and were included into the study, representing 7% of the Danish population in this age group.

At baseline, participants filled in a lifestyle questionnaire. In 1999-2002, participants received a follow-up questionnaire. In total, 45,271 persons (79%) filled in this second questionnaire, and were available for the follow-up part of the present study. Reasons for non-participation were death (14.6%), emigration (3.8%), and no reply (81.7%).

Outcome

Baseline sports information was based on questions on sports activities during summer and winter separately. Participants reported the average number of hours/week spent over the past year. The number of hours spent over each season was averaged.

Information on sports at follow-up was based on questions on low, medium, and high-impact sports during summer and winter separately. Participants reported duration and frequency of the activity, as well as whether they experienced shortness of breath in relation to the activity.

At baseline, sports activities were assigned a metabolic equivalent task (MET) value, according to the compendium of physical activities [20]. This was multiplied by average number of hours/week over summer and winter to get the MET hrs/week for leisure-time sports. At follow-up, again each type of sport was assigned a MET-value, according to the compendium of physical activities [20], based on whether they experienced shortness of breath while active. The MET hrs/week for leisure-time sports was calculated as an average number of hours/week over summer and winter. A detailed description of the physical activity questions and the MET-value assignment is available in [21].

The present study investigates sports by two measures: a dichotomized variable for participation in leisure-time sports (yes/no), and a continuous measure of MET hrs/week for leisure-time sports. Both measures are calculated at baseline and follow-up. Change in leisure-time sports status between baseline and follow-up was categorized as initiation (inactive-active), continued participation (active-active), continued non-participation (inactive-inactive), and cessation (active-inactive), respectively. Change in MET hrs/week was calculated as MET hrs/week at follow-up minus MET hrs/week at baseline.

Exposure assessment

Assessment of traffic noise exposure is previously described in details [17]. Briefly, residential address history was collected for all participants between July 1987 and follow-up, using the Danish civil registration system [22]. Road traffic and railway noise exposure was calculated using SoundPLAN, implementing the joint Nordic prediction method [23]. Using this method, equivalent noise levels can be calculated for each address, when information on a series of traffic and topographic parameters is available. Input variables were: points for noise estimation, and building polygons for all buildings, as well as traffic information on road links (annual average daily traffic, vehicle distribution, travel speed, and road type) and railway links (annual average daily train lengths and types, travel speed, and noise barriers along the railway). We obtained traffic data for all roads with >1,000 vehicles/day from a national road and traffic database [24]. For road traffic noise, no information was available on noise barriers or road surfaces. For assessment of both road traffic and railway noise the terrain was assumed flat, a reasonable assumption in Denmark. Urban areas, roads, and areas with water were assumed to be hard surfaces, whereas all other areas were assumed acoustically porous. 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 day (L_d; 07–19:00h), evening (L_e; 19–22:00h) and night (L_n; 22–07:00h), and expressed as L_{den} (den=day, evening, night). A 5 and 10 dB penalty was applied to evening and night, respectively.

Covariates

The selection of covariates was done *a priori* based on existing literature and biological plausibility. The included confounders were collected at baseline. Sex, age, and smoking were collected as questionnaire data. Education (basic/vocational/higher), cohabiting status (yes/no), and disposable income (household income after taxation and interest, adjusted for number of persons in the household and divided into tertiles) was collected for each participant through the nationwide register Statistics Denmark. Area-level socioeconomic status was classified into three categories (low/medium/high) based on municipality/district information on education, work market affiliation, and income.

Statistical Methods

We used logistic regression models to investigate the association with leisure-time sports status at baseline (yes/no) and with change in status between baseline and follow-up. We used linear regression models to investigate the association between residential traffic noise exposure and baseline MET hrs/week and change in MET hrs/week between baseline and follow-up. In linear regression, all continuous variables were evaluated by investigating linearity both graphically and by linear spline models, and the variance of the residuals was assessed visually by plotting them against the predicted values. We found no significant deviation from linearity for any included variable. Correlations between variables were assessed using Spearman rank correlation coefficients (R_s).

We conducted two types of analyses: Cross-sectional analyses, assessing the association between residential traffic noise and baseline physical activity, and longitudinal analyses, assessing the association between residential traffic noise and changes between baseline and follow-up. In cross-sectional analyses, exposure to traffic noise was modelled as time-weighted average 5 years preceding enrolment, taking into account the time at each residence. In longitudinal analyses, we investigated exposure over the time-period from baseline to follow-up in relation to change in physical activity.

We calculated associations in two models. Model 1; adjusted for age and sex. Model 2; additionally adjusted for area-level socioeconomic status (low/medium/high), education (≤7/8-10/>10 years), income ($1^{st}/2^{nd}/3^{rd}$ tertile), cohabitance (yes/no), and smoking status at baseline (never/former/current). In Model 2 we also adjusted for competing noise sources (road vs. railway). Models on MET hrs/week included a variable for participation in sports (yes/no), and models on linear railway noise included a variable for railway noise exposure (yes/no).

Results for railway and road traffic noise are reported as categorical results (quartiles for road traffic noise; and 0 dB, <55 dB and ≥55 dB for railway noise), as well as changes in the dependent variable per 10 dB increase in noise exposure, with corresponding 95% confidence intervals (CI). The procedures GLM and GENMOD in SAS version 9.3 were used.

RESULTS

In total, 57,053 persons filled in the baseline questionnaire and were available for the cross-sectional study. Of these, 574 were excluded because of cancer before baseline, 1,015 because of missing information on traffic noise exposure, 692 because of missing information on physical activity, 1,171 because of missing information on covariates, and 46 because of implausible values on physical activity (more than 105 hours/week). This rendered an analytical cohort of 53,555 persons (52.4% women).

For longitudinal analyses, out of the original 57,053 participants, we excluded 574 with cancer before baseline, 11,599 who did not answer the follow-up questionnaire, 607 with missing information on traffic noise exposure between baseline and follow-up, 3,584 persons with missing information on physical activity, 926 with missing information on covariates, and 38 with implausible values on physical activity. This rendered a study base of 39,725 persons, with a median follow-up time of 5.3 years (5-95% percentiles: 5.0-5.9).

Table 1 shows the distribution of covariates in groups dichotomized according to mean residential exposure to road traffic noise (above/below 55 dB) and railway noise (yes/no) 5 years preceding baseline. The correlation ($R_{Spearman}$) between railway and road traffic noise was generally low: 0.06. There was a strong correlation between 1- and 5-year noise exposure means for both road traffic and railway noise ($R_{Spearman}$ 0.97 and 0.95). In total, 54.1 % participated in leisure-time sports at baseline and 59.4% at follow-up. The median MET hrs/week at baseline was 27.0 (5-95% percentiles: 3.5-86.0).

Table 1. Characteristics of the Danish Diet, Cancer and Health cohort, according to road and railway traffic noise exposure 5 years before baseline. Median and 5-95 percentile, unless otherwise stated.

	Road traffic noise ≤ 55 dB N = 21,282	Road traffic noise > 55 dB N = 32,273	No railway noise exposure N = 42,491	Railway noise exposure N = 11,064
Male, %	49.4	46.5	48.0	46.2
Age at baseline	56.0 (50.7-64.1)	56.3 (50.8-64.2)	56.2 (50.8-64.2)	56.1 (50.7-64.1)
Education, %				
≤ 7 years	24.6	24.7	27.7	28.5
8-10 years	45.3	45.3	45.1	45.9
> 10 years	30.2	30.0	27.2	25.6
Household income, %				
1st tertile	14.5	23.5	19.2	22.7
2nd tertile	28.8	31.8	30.3	32.1
3rd tertile	56.7	44.7	50.5	45.3
Cohabiting, %	79.4	66.4	73.0	66.0
Area-level socioeconomic status				
High	21.5	21.2	20.1	25.9
Medium	68.9	61.4	65.8	58.7
Low	9.6	17.5	14.1	15.5
Smoking at baseline				
Never	38.0	33.8	35.6	34.9
Former	29.4	27.4	28.5	26.9
Current	32.5	38.8	35.9	38.2
Road traffic noise, dB	51.8 (46.9-54.9)	61.0 (55.5-71.5)	56.5 (48.6-70.1)	57.5 (49.5-69.6)
Railway traffic noise, % exposed	16.6	22.7	0	100

Railway traffic noise, dB[c]	50.0 (32.9-66.8)	49.6 (28.9-65.8)	-	49.7 (30.3-66.3)
[b] Among people exercising [c] Among people exposed to railway noise				

Road traffic noise exposure was associated with non-participation in leisure-time sports at baseline, with a linear estimate of OR 1.10 (1.07-1.13) per 10 dB, which followed a monotonic dose-response relationship. For railway traffic noise the same pattern was seen, with a significant OR for the highest exposure group: 1.08 (1.01-1.16), and a borderline significant linear estimate: OR 1.03 (0.99-1.07) per 10 dB (**Table 2**).

Table 2. Associations between time-weighted mean exposure to traffic noise 5 years before baseline and odds for not participating in leisure-time sports at baseline.

	N	*Crude OR (95 % CI)[a]*	*Adjusted OR (95 % CI)[b]*
Road traffic noise			
L_{den} <= 52.7 dB	13,388	1.00 (Ref)	1.00 (Ref)
L_{den} > 52.7 – 56.8 dB	13,389	1.06 (1.01-1.11)	1.02 (0.97-1.07)
L_{den} > 56.7 – 62.2 dB	13,390	1.21 (1.15-1.27)	1.08 (1.03-1.13)
L_{den} > 62.2 dB	13,388	1.39 (1.33-1.46)	1.15 (1.10-1.21)
Linear estimate, per 10 dB	53,555	1.23 (1.20-1.26)	1.10 (1.07-1.13)
Railway noise			
Not exposed	42,491	1.00 (Ref)	1.00 (Ref)
Exposed, <= 55 dB	7,546	1.03 (0.98-1.09)	1.03 (0.98-1.08)
Exposed, >55 dB	3,518	1.16 (1.08-1.24)	1.08 (1.01-1.16)
Linear estimate, per 10 dB	53,555	1.04 (1.01-1.08)	1.03 (0.99-1.07)
[a] Adjusted for age and sex			

[b] Adjusted as above and further for area-level socioeconomic status (low/medium/high), education (≤7/8-10/>10 years), income (1st/2nd/3rd tertile), cohabitance (yes/no), smoking status at baseline (never/former/current), and in models on road traffic noise also railway noise, and vice versa, and in models of linear railway noise also an indicator for railway noise exposure (yes/no)

We found no association between road traffic noise and MET hrs/week. In contrast, railway noise exposure was significantly associated with a lower MET hrs/week, with an adjusted difference of -0.02 (-0.04; -0.01) per 10 dB in linear analyses (**Table 3**).

Table 3. Associations between time-weighted mean exposure to traffic noise 5 years before baseline and MET hrs/week at baseline.

	N	*Crude difference per 10 dB (95 % CI)[a]*	*Adjusted difference per 10 dB (95 % CI)[b]*
Road traffic noise			
L_{den} <= 52.7 dB	13,388	Ref.	Ref.
L_{den} > 52.7 – 56.8 dB	13,389	-0.04 (-0.30; 0.22)	-0.15 (-0.41; 0.11)
L_{den} > 56.7 – 62.2 dB	13,390	0.21 (-0.05; 0.47)	0.06 (-0.20;0.32)
L_{den} > 62.2 dB	13,388	0.18 (-0.08; 0.44)	0.01 (-0.25; 0.28)
Linear estimate, per 10 dB	53,555	0.10 (-0.04; 0.24)	0.01 (-0.13; 0.16)
Railway noise			
Not exposed	42,491	Ref.	Ref.
Exposed, <= 55 dB	7,546	0.26 (-0.01; 0.52)	0.12 (-0.14; 0.39)
Exposed, >55 dB	3,518	-0.15 (-0.52; 0.22)	-0.25 (-0.62; 0.12)
Linear estimate, per 10 dB	53,555	-0.03 (-0.04; -0.01)	-0.02 (-0.04; -0.01)
[a] Adjusted for age, sex, and participation in sports (yes/no) *[b] Adjusted as above, and further for area-level socioeconomic status (low/medium/high), education*			

(≤7/8-10/>10 years), *income (1st/2nd/3rd tertile), cohabitance (yes/no), smoking status at baseline (never/former/current), and in models on road traffic noise also railway noise, and vice versa, and in models of linear railway noise also an indicator for railway noise exposure (yes/no)*

We found road traffic noise to be associated with an OR of 1.12 (1.07-1.18) for cessation and 0.92 (0.87-0.96) for initiation of leisure-time sports per 10 dB in adjusted analyses (**Table 4**). We found no associations with railway noise.

Table 4. Associations between time-weighted mean exposure to traffic noise between baseline and follow-up and changes in leisure-time sports-participation between baseline and follow-up.

		Road traffic noise		**Railway noise**	
	N	**OR per 10 dB (95 % CI)[c]**	**OR per 10 dB (95 % CI)[d]**	**OR per 10 dB (95 % CI)[c]**	**OR per 10 dB (95 % CI)[d]**
		Leisure time physical activity at baseline			
Continued participation	18,341	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)
Cessation	4,735	1.20 (1.14-1.26)	1.12 (1.07-1.18)	1.01 (0.94-1.07)	0.99 (0.93-1.06)
	No leisure time physical activity at baseline				
Continued non-participation	11,388	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)	1.00 (Ref)
Initiation	5,261	0.88 (0.84-0.93)	0.92 (0.87-0.96)	0.99 (0.93-1.06)	1.01 (0.94-1.07)

[c] *Adjusted for age, sex, and follow-up time*

[d] *Adjusted as c and further for area-level socioeconomic status (low/medium/high), education (≤7/8-10/>10 years), income (1st/2nd/3rd tertile), cohabitance (yes/no), smoking status at baseline (never/former/current), and in models on road traffic noise also railway noise, and vice versa, and in models of linear railway noise also an indicator for railway noise exposure (yes/no)*

We observed no statistically significant changes in MET hrs/week according to either road traffic (β: 0.26 (-0.35; 0.87)) or railway noise (β: 0.02 (-0.06; 0.10) in adjusted analyses).

DISCUSSION

The study found an association between 5-year time-weighted residential traffic noise exposure and the probability of non-participation in leisure-time sports at baseline, which was significant for road traffic noise and borderline significant for railway noise. For road traffic noise, we also found a lower probability of initiating and a higher probability of ceasing sports between baseline and follow-up, with increasing noise levels. We found no association with road traffic noise, but a significant negative association with railway noise in linear analyses of MET hrs/week. Traffic noise was not associated with change in MET hrs/week.

There is increasing evidence for a role of features of the built environment in relation to physical activity [25]. A 2012 review of studies on factors of the built environment and domains of physical activity concluded that there was primarily evidence for an association with physical activity as transportation, rather than leisure-time physical activity [26]. However, a recent cross-sectional study in 12 countries found an association with objectively measured physical activity, using accelerometers [25]. However, none of these studies investigated traffic noise as an environmental factor. A small Dutch study on neighborhood characteristics included area-level traffic noise, as assigned by municipal officials, and found this inversely related with physical activity as transportation among those below 50 years and directly associated with leisure-time walking, cycling or gardening among all participants, but found no association with leisure-time sports [27].

Only one study has previously examined the association between individual-level traffic noise and physical activity; addressing subjectively assessed traffic noise annoyance, and physical activity levels in a population-based Swiss cohort of 3,842 participants, both cross-sectionally and longitudinally [8]. The fact that traffic noise is assessed subjectively, instead of objectively via modelling as in the present study, makes direct comparison of the results difficult. In general, however, the overall conclusions of the two studies are very similar: Both suggest that traffic noise is associated with a decrease in physical activity in cross-sectional as well as longitudinal analyses, with an effect mainly on participation status (yes/no), rather than intensity. A small discrepancy is that we found a significant association between modelled railway noise and participation in leisure-time sports in categorical analyses, and baseline MET hrs/week in linear analyses, whereas the Swiss study found no association with railway noise. Railway noise is generally found less annoying than road traffic noise [28], and the discrepancy may be explained by differences in objective and subjective noise assessment.

For leisure-time sports participation, we found an association with road traffic noise both at baseline and for changes between baseline and follow-up. For railway noise exposure, we only found a significant association with physical activity status at baseline in categorical analyses, and no association in longitudinal analyses. Also, the association with railway noise generally seemed to be of a smaller magnitude than for road traffic noise. Potential explanations for this could be the lower power to investigate this exposure, as only 20.7 % of participants were exposed to railway noise, and only 6.7 % to railway noise >55 dB. As mentioned above, railway noise is generally found less annoying than road traffic noise [28], suggesting that it may not affect physical activity, to the same degree as road traffic noise.

Participants in the present study are relatively settled, with 81% living at the same address through the entire follow-up period. Despite this, we find a higher odds for cessation and a lower odds for initiation of sports between baseline and follow-up for road traffic noise. Thus, the window of effect for traffic noise on physical activity participation seems relatively prolonged, instead of having established itself already at baseline.

In analyses on MET hrs/week, we found no association with road traffic noise, neither at baseline nor between baseline and follow-up. For railway noise we found a significant association with MET hrs/week at baseline in linear analyses. Given the finding of the strongest association with road traffic, rather than railway noise, and leisure-time physical activity in the binary analyses, this is somewhat surprising. The results on MET hrs/week may be true associations, but could also be explained by outcome misclassification: The physical activity questions in the study have primarily been found well-suited to rank individuals according to physical activity level [29-31], whereas they only crudely capture elements of type, intensity, duration, and frequency [31]. This suggests that the calculation of MET hrs/week may be more susceptible to information bias than binary grouping of participation in leisure-time sports into yes/no, which may be more accurately reported. Potentially, this information bias may be even stronger in analyses on change in physical activity levels, as information bias may affect both information on physical activity at baseline and at follow-up, rendering the difference between them fraud with an even higher level of bias.

As the association between traffic noise and physical activity is a new area of research, little is known about relevant biological mechanisms, which could explain an association. We propose that the effects could be exerted through a direct pathway; by rendering the nearby environment unappealing for physical activity, but also through an indirect pathway of sleep deprivation or stress. Unfortunately, however, the study did not include information on where the leisure-time physical activity took place: This may not necessarily be conducted close to the residence where traffic noise is modelled, but could also take place in indoor gyms, swimming pools etc., where traffic noise levels is dampened considerably. Furthermore, we did not have information on sleep duration or quality of the participants, or of other external stressors, and hence, these pathways are merely speculative.

The study strengths include the large study population, and the excellent modelling of traffic noise, based on detailed address history. We used the well-validated Nordic Prediction Model, which has been a standard method for estimation of traffic noise in the Nordic countries for many years [23, 32]. The questions on physical activity have been validated, and found to rank individuals satisfactorily with regard to physical activity level [29-31]. Study limitations include that despite using a well-validated noise exposure model, our findings may still be subjected to exposure misclassification, as we only had information on exposure at the most exposed façade of the house, not taking into account bedroom location, time spent at home, window opening habits, and hearing impairment, which may affect the true exposure. Also, the participation rate at baseline was 36 % [19]. The population is thus a selected population, and they have generally been found of higher socioeconomic status than non-participants [19], a feature which was even further strengthened when comparing participants and non-participants at follow-up [33]. This may be of particular relevance in our study, since socioeconomic variables (education, income, and area-level socioeconomic position) seems the strongest confounders in our models. In general, there was a large difference in estimates between unadjusted and adjusted models, and the strong role of the covariates entails a risk of residual confounding, which should be kept in mind when interpreting the findings. Another limitation is that we lack information on whether physical activity is performed in close proximity to the residence, where traffic noise is modelled. We also lacked information on nearby access to green areas, which may both function as a venue for exercising, but has also been proposed to reduce long-term annoyance to road traffic noise and the prevalence of stress-related symptoms from this [34], and could thus potentially confound the association between noise and physical activity. Finally, the wording of the questions on physical activity was not identical at baseline and follow-up. This could potentially introduce information bias in the analyses on changes between baseline and follow-up.

In conclusion, long-term exposure to residential road traffic noise, and to a lesser degree also railway noise, may be negatively associated with participation in leisure time sports. Given the high proportion of physically inactive people worldwide, and its strong negative impact on health, the study proposes a new venue for interventions against physical inactivity, which could potentially improve public health. However, further research is necessary before firm conclusions can be drawn.

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