# Exposure to road traffic noise and risk for behavioral problems in 7-year old children: a cohort study

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**Summary**

Exposure to traffic noise has been associated with adverse effects on neuropsychological development in children, but the results with regard to behavioral problems are inconsistent. In this study, we investigated associations between residential road traffic noise exposure and behavioral problems in 7-year old children using data from a national birth cohort in which we identified 46,940 children with complete information on both behavioral problems at 7 years of age and address history from conception to 7 years of age. Road traffic noise ($L_{den}$) was modeled at all present and historical addresses and behavioral problems were assessed by the Strengths and Difficulties Questionnaire. Associations between pregnancy and childhood exposure to noise and behavioral problems were analyzed by multinomial logistic regression models and adjusted for potential confounders. We found that for mean time-weighted exposure from birth to 7 years of age, a 10 dB higher road traffic noise was associated with a 7 % higher risk for scoring abnormal (95% CI: 1.00-1.14) compared to normal scores on the total difficulties score. A 5 % higher risk for scoring borderline (95% CI: 1.00-1.10) and a 10 % higher risk for scoring abnormal (95% CI: 1.03-1.18) were found on the hyperactivity/inattention subscale. Exposure to road traffic noise during the pregnancy period was not associated with child behavioral problems at 7 years of age. In conclusion, this study indicates that residential road traffic noise in early childhood may increase the risk for behavioral problems, particularly hyperactivity/inattention symptoms.

**PACS no. 43.50.Qp, 43.50.Rq**

## 1. Introduction

### 1.1. Background

Exposure to traffic noise is considerable in many parts of the world and has been associated with adverse effects on neuropsychological development in children. Most studies have focused on learning and cognitive performance with consistent findings of impairment in reading and memory [1]. Only few studies have investigated associations between exposure to traffic noise and child behavioral problems and the results are inconsistent. Two studies of schools near Heathrow airport found, respectively no association [2] and a weak association [3] between school exposure to airport noise and hyperactivity and psychosocial morbidity. A study of schools near airports in three European countries found school exposure to airport noise to be associated with an increased score of hyperactivity whereas exposure to road traffic noise at the schools was associated with lower scores for conduct problems [4]. Only one study has investigated associations between residential exposure to road traffic noise and behavioral problems in children, with findings of an increased risk for hyperactivity and possibly emotional symptoms [5].

Residential exposure to traffic noise might be a more relevant exposure window than exposure at school with regard to the investigated behavioral problems. Children spend more time at home than at the school, and night time exposure might be important, as traffic noise at normal urban levels has been associated with sleep disturbance [6]. In children, sleep disturbance and sleep problems is suspected to affect child behavior [7, 8], possible through sleep deficits, which affects the frontal lobe, the part of the brain region, that among other functions, control behavior and emotions [8].

No studies have investigated associations between exposure to traffic noise during the pregnancy period and behavioral problems. However, noise is an environmental stressor and maternal exposure to stress during pregnancy has been suggested to be associated with psychological effects in children, including cognitive, behavioral and emotional development [9]. A potential mechanism of action is activation of the maternal hypothalamic-pituitary-adrenal axis, leading to increased levels of maternal cortisol [10], which can pass the fetal-placental barrier and subsequently might influence the fetal nervous system and emotional and cognitive functioning of the child.

The aim of this study was to investigate the associations between exposure to road traffic noise at the residence during pregnancy and early life and behavioral problems in 7-year-old children.

### 1.2. Materials and Methods

The study is based on the Danish National Birth Cohort (DNBC) [11]. During 1996-2002 pregnant women, who intended to carry their pregnancy to term, who spoke Danish and who had a permanent address in Denmark, were invited to participate in the DNBC. Participation involved two prenatal telephone interviews and the first interview (12th pregnancy week) included questions regarding alcohol consumption and smoking habits as well as questions related to maternal mental health. Furthermore, the parents received a follow-up questionnaire when the child was 7 years old. This questionnaire included questions regarding behavioral problems of the child and was based on the Strengths and Difficulties Questionnaire (SDQ).

Behavioral problems at 7 years of age were assessed by the Danish parent-reported version of the SDQ (SDQ-Dan) [12]. The SDQ encompasses the child's behavior in the past 6 months and is used worldwide for clinical and research purposes. The SDQ consists of 25 items and generates scores within five subscales: emotional symptoms, conduct problems, hyperactivity/inattention, peer relationship problems and pro-social behaviors. Each subscale is covered by 5 items, which can be rated with a three-point scale option; '*not true'* (0), '*somewhat true'* (1) or '*certainly true'* (2) and summing up the ratings generates each subscale score. The total difficulties score is obtained by summing up all subscale score except the pro-social behavior score. In the present study, the total difficulties score and the scores within the subscales: emotional symptoms, conduct problems, hyperactivity/inattention and peer relationship problems were divided into the categories: *normal, borderline* or *abnormal,* by the use of the normative age and sex specific cut-off scores for Danish children (www.sdqinfo.org).

Home address history during pregnancy and from birth until 7 years of age was collected using the

Danish civil registration system. Road traffic noise exposure was calculated for the years 1995, 2000, 2005 and 2010 for all present and historical addresses using SoundPLAN, which calculates road traffic noise in accordance with the Nordic prediction method [13]. Input variables for the noise model included geographical coordinates and height (floor) for each address, data on road lines, information on yearly average daily traffic, vehicle distribution (light, heavy), traffic speed and road type, obtained form DCE-Danish Centre for Environment and Energy, Aarhus University and from The Danish Road Directorate. Data on all Danish building polygons were provided by the Danish Geodata Agency. We assumed that the terrain was flat and that urban areas, roads, and areas with water were hard surfaces, whereas all other areas were acoustically porous.

Road traffic noise was calculated as the equivalent continuous A-weighted sound pressure level ($L_{Aeq}$), at the most exposed façade of the dwelling at each address for the day ($L_d$; 07:00-19:00 h), evening ($L_e$; 19:00-22:00 h) and night ($L_n$; 22:00-07:00 h). Road traffic noise was expressed as $L_{den}$ by applying a 5-dB penalty for the evening and a 10-dB penalty for the night. All values below 40 dB were set to 40 dB, as this was considered the lower limit of road traffic noise.

Residential exposure to railway noise was calculated for the years 1995, 2000, 2005 and 2010 for all present and historical addresses using SoundPLAN, which calculated railway noise in accordance with NORD2000, a Nordic calculation method for prediction of noise propagating for railway traffic noise (www.soundplan.dk). Geographical coordinates and height (floor) for each address were used in the noise model, including railway lines, information on annual average daily train lengths, train types and travel speed, which were obtained from the railway enterprise. Building polygons as well as all noise barriers along the railway were included in the model. Railway traffic noise was expressed as $L_{den}$ at the most exposed façade of the dwelling. Railway noise exposure below 20 dB was set to 0 in the analyses, as we estimated overall background noise to be no lower than 20 dB.

The noise impact from all Danish airports and airfields was determined from information about noise zones (5 dB categories), obtained from local authorities. The programs DANSIM (Danish Airport Noise Simulation Model) and INM3 (Integrated Noise Model), which fulfill the Nordic criteria for air traffic noise calculation, were used. Curves for airport noise were transformed into digital maps and linked to each address history by geographical coordinates.

Air pollution was calculated at all geographical coordinates using the Danish AirGIS modeling system, which calculates air pollution as the sum of: local air pollution from traffic in streets based on the Operational street Pollution Model (OSPM); the urban background contribution based on an area dispersion model; and contributions from the regional background [14]. We used $NO_x$ levels as an indicator of air pollution, which was calculated based on data for the relevant years about traffic data for individual road lines, emission factors for Danish car fleet, street, and building geometry, including building height as well as meteorological data. Air pollution exposure was expressed as the yearly mean concentration of $NO_x$ ($\mu g/m^3$).

Associations between exposure to residential road traffic noise and risk for behavioral problems at 7 year of age were analyzed by multinomial logistic regression models. Exposure to road traffic noise was modeled as time-weighted mean during: a) pregnancy and b) from birth to 7 years of age. Exposure to railway noise was modeled as continuous at: a) time of birth and b) time of filling in the SDQ (7 years).

Associations were estimated as odds ratios (OR) with corresponding 95 % confidence intervals (CI) for being classified in the borderline or in the abnormal category per 10 dB increase in $L_{den}$ road, using the normal category as a reference. The OR's were calculated as crude, and adjusted for potential confounders, selected *a priori*. Models were first adjusted for sex, age at filling in the SDQ (years), gestational age (<37, ≥37 weeks), birth weight (<2500, ≥2500 grams), maternal age at delivery (years), parity (0, 1, ≥2), smoking (no/yes) and average alcohol consumption (<1, ≥1 drinks per week) during 1$^{st}$ trimester, level of education (highest attained education one year before conception: basic (7-12 years of primary, secondary and grammar-school), vocational (10-12 years of education) and higher (≥13 years of education)), disposable income (quintiles, household income after taxation and interest per person, adjusted for number of persons in the household and deflated according to the 2000 value of the Danish crown), railway (no, ≤60 dB, >60 dB) and airport noise (yes/no) at birth (for analyses of exposure during pregnancy) and at 7 year of age (for analyses of childhood exposure) and self-reported maternal mental health problems during 1st trimester (yes/no). Secondly, analyses were further adjusted for time-weighted mean of $NO_x$ (µg/m$^3$) corresponding to each exposure window. All information on socioeconomic position (SEP) was obtained from the national register, Statistic Denmark.

All analyses were done in SAS (version 9.3, SAS Institute, Inc., Cary. NC, USA).

correlation (Rs) between $L_{den}$ road during pregnancy and childhood was 0.74, and between $L_{den}$ road and air pollution ($NO_x$) the correlation was 0.59 for the pregnancy period and 0.42 for the period from birth until 7 years of age. There was a high correlation between the $L_{den}$ and $L_n$ road for the pregnancy period (0.97) and during childhood (0.90).

For time-weighted mean exposure from birth to 7 year of age, we found a 10 dB higher exposure to

Table I. Characteristics of the study population by case status using the total difficulties score

| Co-variates | Cohort N = 46,940 | Borderline cases [a] N = 5,309 | Abnormal cases [a] N = 3,770 |
|---|---|---|---|
| Boys (%) | 51.1 | 54.4 | 52.3 |
| Age at SDQ (years) [b,c] | 7.13 (7.03-7.41) | 7.14 (7.03-7.41) | 7.14 (7.03-7.41) |
| < 37 gestational weeks at birth (%) | 4.2 | 4.9 | 6.4 |
| < 2500 grams at birth (%) | 2.6 | 3.3 | 4.6 |
| Maternal age at birth (years) [b] | 30.3 (23.9-37.3) | 29.5 (23.1-37.3) | 29.1 (22.0-37.3) |
| Nulliparous (%) | 49.9 | 56.7 | 56.0 |
| Uniparous (%) | 34.6 | 31.8 | 32.7 |
| Multiparous (%) | 15.5 | 11.5 | 11.3 |
| Smoking during 1st trimester (yes) (%) | 24.1 | 28.5 | 34.2 |
| Alcohol during 1st trimester: ≥1 drinks per week (%) | 11.8 | 10.2 | 9.9 |
| Basic education (7-12 years) (%) | 13.3 | 18.7 | 26.9 |
| Vocational education (10-12 years (%) | 52.8 | 54.8 | 53.9 |
| Higher education (≥ 13 years) (%) | 33.9 | 26.5 | 19.2 |
| Low disposable income (%) | 17.9 | 18.7 | 21.3 |
| Medium disposable income (%) | 30.7 | 31.4 | 31.9 |
| High disposable income (%) | 51.4 | 49.9 | 46.8 |
| Maternal mental health problems (yes) (%) | 1.1 | 1.5 | 2.2 |
| Road traffic noise (dB) [b,d] | 57.9 (50.3-68.1) | 58.1 (50.5-68.2) | 58.6 (50.6-68.1) |
| Railway noise at 7 years of age (13% exposed) (dB) [b] | 48.4 (34.6-64.8) | 47.7 (34.8-65-8) | 49.6 (34.7-66.0) |
| Air pollution ($NO_x$, µg/m$^3$) [b d] | 12.2 (10.9-34.5) | 12.2 (10.9-33.5) | 12.3 (10.9-33.3) |

[a] Total difficulties score, [b] Median (5–95 percentiles), [c] SDQ: Strengths and difficulties questionnaire, [d] Mean time-weighted exposure from birth until 7 years of age

## 2. Results

A total of 57,281 mother and child pairs provided information on SDQ, and we included only the first enrolled pregnancy (54,103) and excluded 2,272 mothers with multiple pregnancies, 1,833 with incomplete information on behavioral problems, 170 with missing noise exposure data and 2,888 with incomplete information on potential confounders, leaving a study cohort of 46,940 children.

Characteristics of the study population and cases classified as borderline or abnormal on the total difficulties score are summarized in Table 1.

Compared with the cohort, borderline and abnormal cases were more likely to be boys, the first born child, exposed to maternal smoking during 1st trimester and have a mother with lower educational level and disposable income. The road traffic noise to be associated with a 7% higher risk for scoring abnormal (95% CI: 1.00-1.14) on the total difficulties score (Table II). On the hyperactivity/inattention subscale a 10 dB higher road traffic noise exposure was associated with a 5% higher risk for scoring borderline (95% CI: 1.00-1.10) and a 10% higher risk for scoring abnormal (95% CI: 1.03-1.18) as compared with normal scores in the adjusted models (Table II).

Further adjustment for $NO_x$ resulted in small increases in the estimates (results not shown). $NO_x$ exposure in itself was found not to be associated with behavioral problems (results not shown).

There were no clear associations between exposure to road traffic noise during pregnancy and behavioral problems, though there was an indication of an inverse association for scoring borderline on the total difficulties score: OR: 0.95 (95% CI: 0.90-0.99).

Table II. Associations between exposure to road traffic noise ($L_{den}$, per 10 dB increase) during early childhood and risk for scoring behavioral borderline or abnormal

| | | | Exposure to road traffic noise ($L_{den}$) from birth to 7 years of age [a] | |
|---|---|---|---|---|
| Strengths and difficulties score | | N | Crude OR (95% CI) | Adjusted OR (95% CI) [b] |
| Total difficulties score | Normal | 37,861 | 1.00 | 1.00 |
| | Borderline | 5,309 | 1.07 (1.01, 1.13) | 1.00 (0.95, 1.06) |
| | Abnormal | 3,770 | 1.17 (1.11, 1.25) | 1.07 (1.00, 1.14) |
| Emotional symptoms | Normal | 40,245 | 1.00 | 1.00 |
| | Borderline | 3,099 | 1.12 (1.05, 1.19) | 1.03 (0.96, 1.10) |
| | Abnormal | 3,596 | 1.11 (1.04, 1.18) | 0.98 (0.92, 1.05) |
| Conduct problems | Normal | 40,374 | 1.00 | 1.00 |
| | Borderline | 4,045 | 1.02 (0.97, 1.09) | 1.01 (0.96, 1.07) |
| | Abnormal | 2,521 | 1.10 (1.03, 1.18) | 1.05 (0.98, 1.14) |
| Hyperactivity/inattention | Normal | 37,799 | 1.00 | 1.00 |
| | Borderline | 6,097 | 1.09 (1.05, 1.15) | 1.05 (1.00, 1.10) |
| | Abnormal | 3,044 | 1.18 (1.11, 1.26) | 1.10 (1.03, 1.18) |
| Peer relationship problems | Normal | 37,690 | 1.00 | 1.00 |
| | Borderline | 5,243 | 1.06 (1.01, 1.12) | 1.05 (0.99, 1.10) |
| | Abnormal | 4,007 | 1.12 (1.06, 1.19) | 1.06 (0.99, 1.12) |

[a] Mean time-weighted exposure, [b] Adjusted for sex, age at SDQ, gestational age, birth weight, maternal age at delivery, parity, educational level, disposable income, smoking and alcohol consumption during 1st trimester, railway and airport noise at 7 year of age and self-reported mental health problems during 1st trimester (yes/no)

## 3. Discussion

In this study we found that cumulative exposure during childhood to residential road traffic noise increased the risk for behavioral problems at 7 years of age, particularly hyperactivity/inattention symptoms. Hyperactive children are normally more easily distracted by background noise [15], and it seems possible that traffic noise may exacerbate these children's difficulties, thereby making an existing tendency towards hyperactivity worse or more obvious. This result is in line with a similar though smaller study that reported road traffic noise at home to be associated with more hyperactivity/inattention symptoms in 10 year old children [5]. Published studies on airport and road traffic noise at schools are less consistent, with findings of both positive associations between traffic noise and hyperactivity/inattention symptoms [3, 4] and findings of no association [2]. An explanation for this inconsistency might be that exposure to traffic noise at home is more hazardous than school exposure, potentially because children typically spend more time at home than at school, and that nighttime exposure to noise might be particularly hazardous as it disturbs sleep [6], which is suspected of affecting child behavior [7, 8]. However, we had no information on sleep disturbance among the children and could not separate the effects of nighttime exposure to road traffic noise from daytime exposure due to the high correlation and therefore, speculations regarding hazardous effects of nighttime noise in the present study are hypothetical.

We found no consistent associations between exposure to road traffic noise at home during pregnancy and behavioral problems. The only significant finding was an inverse association for scoring borderline on the total difficulties score, which we believe to be a chance finding as this is opposite our hypothesis and only found for the borderline and not for the abnormal score. Our result may suggest that prenatal stress due to traffic noise is not important in relation to this outcome.

Strengths of our study include the large study population, with information on various potential confounders obtained from questionnaires and nationwide registers, as well as modeled air pollution and access to address histories from conception to 7 years of age, which makes it possible to investigate different exposure time-windows. However, some limitations have to be considered. This study is cross sectional, with no follow-up information on outcome, and thus the temporal aspect of causality cannot be determined which prevent us from making any causal inferences regarding the effect of noise on the development of behavioral problems. We used the Nordic prediction method for noise estimation, but noise estimation depends on accurate input data and we had no information on noise barriers or road surface in the modeling of road traffic noise. This could result in exposure misclassification, but such misclassification is believed to be non-differential, and, in most situations, this would influence the estimates towards the neutral value. Another limitation is that we had information only on residential addresses of the child and not, for example, if the parents were divorced or living apart, the address of the other parent, by whom the child could be partly staying. Moreover, we had no information on whether the child's bedroom faced a busy road or backyard, or on noise insulation or window opening habits, which all influence the child's personal exposure to noise. Behavioral problems were based on the parent-reported version of the SDQ and recalling the child's behavior in the past 6 month, may be associated with some recall bias. However, we do not expect recall to be associated with exposure to residential traffic noise exposure and therefore not give rise to any systemic bias. Lastly there might be residual confounding by SEP. However, we have detailed information from questionnaires and registers on the most important confounders. Also in Denmark a high proportion of highly educated people live in central urban areas with relative high traffic noise, and therefore differences in noise exposure according to SEP are not pronounced in the present study: low, medium and highly educated mothers were exposed to medians of 58.8, 57.9 and 57.7 dB road traffic noise, respectively, suggesting that residual confounding by SEP is not a major problem in the present study.

## 4. Conclusion

This study indicates that exposure to residential road traffic noise from birth until 7 years of age is associated with hyperactivity/inattention symptoms, whereas exposure to noise during the pregnancy period showed no associations with behavioral problems in childhood.

### Acknowledgement

The European Research Council, EU 7th Research Framework programme supported this study by grant number *281760.* The Danish National Research Foundation has established the Danish Epidemiology Science Centre that initiated and created the Danish National Birth Cohort. The cohort is furthermore a result of a major grant from this foundation. Additional support for the Danish National Birth Cohort is obtained from the Pharmacy Foundation, the Egmont Foundation, the March of Dimes Birth Defects Foundation, the Augustinus Foundation, and the Health Foundation. The 7-year follow-up received support from the Lundbeck Foundation (195/04) and the Danish medical Research Council (SSVF 0646).

### References

[1] S.A. Stansfeld et al.: Aircraft and road traffic noise and children's cognition and health: a cross-national study. Lancet. (2005)1942-1949.

[2] M.M. Haines et al.: Chronic aircraft noise exposure, stress responses, mental health and cognitive performance in school children. Psychol Med. (2001) 265-77.

[3] M.M. Haines et al.: The West London Schools Study: the effects of chronic aircraft noise exposure on child health. Psychol.Med. (2001) 1385-1396.

[4] S. Stansfeld et al.: Aircraft and road traffic noise exposure and children's mental health. Journal of Environmental Psychology. (2009) 203-207.

[5] C.M. Tiesler et al.: Exposure to road traffic noise and children's behavioural problems and sleep disturbance: results from the GINIplus and LISAplus studies. Environ.Res. (2013) 1-8.

[6] S. Pirrera et al.: Nocturnal road traffic noise: A review on its assessment and consequences on sleep and health. Environ.Int. (2010) 492-498.

[7] A.M. Gregory and A. Sadeh: Sleep, emotional and behavioral difficulties in children and adolescents. Sleep Med.Rev. (2012) 129-136.

[8] J. Quach et al.: Outcomes of child sleep problems over the school-transition period: Australian population longitudinal study. Pediatrics (2009) 1287-1292.

[9] R. Graignic-Philippe et al.: Effects of prenatal stress on fetal and child development: A critical literature review. Neurosci.Biobehav.Rev.(2014) 137-162.

[10] R. Beijers et al.:Mechanisms underlying the effects of prenatal psychosocial stress on child outcomes: beyond the HPA axis. Eur Child Adolesc Psychiatry. (2014) 943-956.

[11] J. Olsen et al.: The Danish National Birth Cohort--its background, structure and aim. Scand.J.Public Health. (2001) 300-307.

[12] R. Goodman: The Strengths and Difficulties Questionnaire: a research note. J.Child Psychol.Psychiatry. (1997) 581-586.

[13] H. Bendtsen: The Nordic Prediction Method for road traffic noise. (1999) 331-338.

[14] M. Ketzel et al.: Evaluation of AirGIS: a GIS-based air pollution and human exposure modelling system.International Journal of Environmental Pollution. (2011) 226-238.

[15] L.C. Gray et al.: Continuum of impulsiveness caused by auditory masking. Int J Pediatr Otorhinolaryngol. (2002) 265-72.