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Exposure to road traffic noise and children's behavioural problems and sleep disturbance: Results from the GINIplus and LISAplus studies

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ABSTRACT

Background: Exposure to transportation noise showed negative health effects in children and adults. Studies in children mainly focussed on aircraft noise at school.
Objectives: We aimed to investigate road traffic noise exposure at home and children's behavioural problems and sleeping problems.
Methods: 872 10-year-old children from Munich from two German population-based, birth-cohort studies with data on modelled façade noise levels at home and behavioural problems were included. Noise was assessed by the day–evening–night noise indicator L_{den} and the night noise indicator L_{night}. Behavioural problems were assessed by the Strengths and Difficulties Questionnaire (SDQ). A subgroup ($N=287$) had information on sleeping problems. Continuation ratio models (logistic regression models) adjusted for various covariates were applied to investigate the association between interquartile range increases in noise and SDQ scales (sleeping problems).
Results: Noise measured by L_{den} at the most exposed façade of the building was related to more hyperactivity/inattention (continuation odds ratio (cOR)=1.28(95%-confidence interval(CI):1.03–1.58). Noise at the least exposed façade increased the relative odds for having borderline or abnormal values on the emotional symptoms scale, especially the relative odds to have abnormal values for a subject with at least borderline values (L_{den}:cOR=2.19(95% CI:1.32–3.64). Results for L_{night} were similar. Nocturnal noise at the least exposed façade was associated with any sleeping problems (odds ratio (OR)=1.79(95% CI=1.10–2.92)).
Conclusions: Road traffic noise exposure at home may be related to increased hyperactivity and more emotional symptoms in children. Future longitudinal studies are required to explore noise exposure and behavioural problems in more detail, especially the role of sleep disturbances.

1. Introduction

Exposure to transportation noise from aircraft, road traffic or trains showed negative health effects in adults and children (Clark and Stansfeld, 2007; WHO, 2009; WHO, 2011). In children, most studies to date focussed on investigating the effects of exposure to aircraft noise. Consistent results were found for impaired cognitive function such as reading comprehension and recognition memory in children exposed to aircraft noise at school (Stansfeld et al., 2010, 2005). Increased blood pressure (Paunovic et al., 2011) and annoyance reactions (van Kempen et al., 2009) were also reported to be associated with children's exposure to noise. However, the results for the association between noise exposure and children's psychological well-being were partly inconsistent. Some studies investigating the effect of exposure to aviation noise reported no association with children's mental health or depression and anxiety symptoms (Haines et al., 2001b, 2001c; Stansfeld et al., 2005). In contrast, Evans et al. (1995) reported that children living in aircraft-exposed

Abbreviations: SDQ, strengths and difficulties questionnaire; OR, odds ratio; cOR, continuation odds ratio; CI, confidence interval; L_{den}, day–evening–night equivalent noise level; L_{night}, night equivalent noise level; max(L_{den}), L_{den} at the most exposed façade of the children's home address; min(L_{den}), L_{den} at the least exposed façade of the children's home address; max(L_{night}), L_{night} at the most exposed façade of the children's home address; min(L_{night}), L_{night} at the least exposed façade of the children's home address

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communities showed lower levels of psychological well-being measured by a quality of life measurement instrument. Lercher et al. (2002) reported that exposure to noise (combined noise indicator for rail and road traffic) at home was significantly associated with an impairment of children's self-reported mental health but only in a subgroup of children who were either born preterm or had a low birth weight. In The West London Schools Study, Haines et al. (2001a) observed a weak association between aircraft noise at school and hyperactivity/inattention scores of the Strengths and Difficulties Questionnaire (SDQ). The Road Traffic and Aircraft Noise Exposure and Children's Cognition and Health (RANCH) study, a cross-national study around three large European airports, found no association between either daytime exposure to aircraft or road traffic noise at school and children's overall mental health measured by the total difficulties score of the SDQ (Stansfeld et al., 2005). However, significant associations between transportation noise and scores on the subscales of the SDQ were observed: Exposure to aviation noise was associated with higher hyperactivity/inattention scores and road traffic noise showed lower values for conduct problems (Stansfeld et al., 2009). In the London subgroup of the RANCH study population, nocturnal exposure to aircraft noise at home did not affect children's mental health, neither on the total difficulties score of the SDQ nor on any of its subscales (Stansfeld et al., 2010). Due to the results of Lercher et al. (2002), Crombie et al. (2011) investigated the potential modification of the association between noise exposure at school and children's mental health by early biological risk (born prematurely or low birth weight) in the RANCH study. Associations between aircraft noise exposure at school and higher values on the hyperactivity/inattention scale and road traffic noise and decreased conduct problems scores were observed. Whereas the latter association withstood the adjustment for early biological risk, the former did not.

The aim of the present study was to provide further insight into the effects of noise exposure on children's psychological well-being focussing on road traffic noise exposure at home. In a subgroup, the association between exposure to nocturnal noise and sleeping problems was investigated.

2. Material and methods

2.1. Study population

The Influence of Life-style factors on the development of the Immune System and Allergies in East and West Germany Plus the influence of traffic emissions and genetics (LISAplus) and the German Infant Study on the influence of Nutrition Intervention Plus environmental and genetic influences on allergy development (GINIplus) are ongoing population-based birth-cohort studies.

For LISAplus, the parents of neonates admitted to maternity hospitals in four German cities (Munich, Leipzig, Wesel and Bad Honnef) were contacted for participation in the study. A total of 3097 healthy, full-term neonates were recruited in the study between December, 1997 and January, 1999. Screening, recruitment and exclusion criteria were described for example by Heinrich et al. (2002) and Zutavern et al. (2006).

The GINIplus study aimed to study the influence of nutrition intervention in infancy, environmental exposures and genetic factors on the development of allergies. Between September, 1995 and June, 1998, a total of 5991 healthy, full-term infants born in Munich and Wesel, Germany, were recruited in the GINIplus study. The study population consists of an interventional and an observational group. Children with family history of allergy were assigned to the intervention group and the observational subgroup comprises children who either have a negative family history of allergy or have a family history of allergy but whose parents did not give consent for participation in the intervention trial. A description of the study design has been published previously (von Berg et al., 2010). The LISAplus and GINIplus studies were approved by the local ethics committees and written consent was obtained from the parents of all study participants.

Inclusion criteria for the current study were participation at the 10-year follow-up, the availability of noise exposure data (home address in the city of Munich) and information on behavioural problems. Additionally, we excluded children who were living for less than 1 year at their current place of residence. A total of 2949 children from Munich were recruited at birth for GINIplus from which 1730 (58.7%) participated at the follow-up 10 years later. In LISAplus, 1467 children from Munich were originally recruited and 940 (64.1%) were followed up to 10 years. After exclusion of children not meeting the above-mentioned criteria, the study population for the current study consists of 872 children (583 from GINIplus and 289 from LISAplus). For 287 of the 289 LISAplus children additional information on sleeping problems was available.

2.2. Noise exposure measurement

Road traffic noise data used within the current study is based on the Munich noise map, which was created for the year 2007. Birk et al. (2011) provides some details on the road traffic noise modelling procedure. CadnaA software ("Computer Aided Noise Abatement", see DataKustik website: 〈http://www.datakustik.com/index.php?id=52&L=1〉) was used for the calculations based on a 3-dimensional terrain model to account for multiple reflections and shielding from objects, including houses and other noise barriers. Modifying effects of traffic noise protection measures such as noise shield walls and also of buildings were considered in the noise model. Two noise indicators defined according to the European Environmental Noise Directive (Directive 2002/49/EC, 2002) and its implementation into German law-the 34th Federal Immission Control Ordinance (34. BImSchV, 2006)-were available for all children studied. First, the night noise indicator L_{night} is defined as the A-weighted long-term average sound level determined over all night periods (8 h: 10 p.m.–6 a.m.) of the year. This indicator can be used to measure sleep disturbance by noise. Second, the day–evening–night noise indicator L_{den} can be used to assess overall noise annoyance and accounts for increased levels of disturbance by noise during the evening and night times. It is defined by

$$L_{\mathrm{den}} = 10\lg\frac{1}{24}\left(12 \times 10^{\frac{L_{\mathrm{day}}}{10}} + 4 \times 10^{\frac{L_{\mathrm{evening}}+5}{10}} + 8 \times 10^{\frac{L_{\mathrm{night}}+10}{10}}\right)$$

where L_{night} is defined as above and L_{day} and L_{evening} are the A-weighted long-term average sound levels, determined over all day (12 h: 6 a.m.–6 p.m.) and evening (4 h: 6 p.m.–10 p.m.) periods of the year, respectively (Directive 2002/49/EC, 2002; WHO, 2011). The German definition of noise indicators (34. BImSchV, 2006) differs slightly from the proposed definitions in the Directive 2002/49/EC, 2002 in terms of a 1 h earlier beginning of the day, evening and night period. A-weighted sound pressure levels (expressed as dB(A)) are applied as they account for the fact that the same sound pressure level is perceived differently at different frequencies by the human ear (Ouis, 2001). Noise exposure of the children at their home address was defined by maximum and minimum levels of L_{den} and L_{night} calculated over all noise levels at façade grid points for each building representing the noise at the most (max(L_{den}) and max(L_{night}), respectively) and least exposed façade (min(L_{den}) and min(L_{night}), respectively).

2.3. Health outcomes

Behavioural problems at the age of 10 years were assessed by the German parent-reported version of the SDQ (Goodman, 1997; Goodman et al., 1998; Woerner et al., 2002; Woerner et al., 2004). The SDQ is an internationally disseminated and validated behavioural screening questionnaire for 3-to 16-year-olds. The five dimensions (emotional symptoms, conduct problems, hyperactivity/inattention, peer relationship problems and prosocial behaviour) are covered by five SDQ items each, resulting in 25 items total. A three-point scale with response options 'not true' (0), 'somewhat true' (1) and 'certainly true' (2) was used for scoring each item (e.g. 'Many worries, often seems worried.'). Positively worded items were reverse-scored. Ratings of the subscale items are summed to give subscale scores. According to the standard scoring instructions on 〈http://www.sdqinfo.org〉, subscale scores were prorated in case at most two out of five scale items have been omitted. The total difficulties score is obtained by summing all subscale scores except for the prosocial behaviour score. The total difficulties score and the subscale scores were categorised into normal, borderline or abnormal according to cut-off points recommended for German samples (Woerner et al., 2004). The analyses in the present study are restricted to the four problem scales of the SDQ (excluding prosocial behaviour) and the total difficulties score. Current sleeping problems at the age of 10 years were assessed for children of the LISAplus cohort. Three dichotomous variables measure the presence of any sleeping problems and, in more detail, difficulties to fall asleep or difficulties sleeping through the night.

2.4. Definition of covariates

Basic characteristics of the children in the study such as sex, age and study (GINIplus-interventional group or observational group, LISAplus) were extracted from questionnaires. Additional covariates potentially related to confounding were chosen based on previous similar studies (e.g. Lercher et al., 2002; Crombie et al. 2011). Parental educational level and single parent status were included to reflect the socioeconomic status of the family of the study child.

Television/computer usage was used as a proxy variable for children's physical activity as less physical activity was reported to be associated with poorer mental health (e.g. Biddle and Asare, 2011). Parental educational level was categorised based on duration of education and defined as follows: both parents with less than 10 years of schooling as 'low', at least one parent with 10 years of schooling as 'medium' and at least one parent with more than 10 years of schooling as 'high'. Mother's age at birth of the study child was assigned to three age groups with cut-offs at the 25th and 75th percentiles (30 and 35 years). At the 10-year follow-up single parent status and the time the child has usually spent in front of a screen (e.g. television or computer) in the previous year ('low' was defined as one hour or less per day in summer and two hours or less per day in winter compared to 'high') were assessed. For the analysis on sleeping problems, two further variables measure whether the child sleeps alone in his/her room and whether a window of the child's bedroom is oriented to the side of the house facing the street.

2.5. Statistical analysis

We analysed the associations between interquartile range (IQR) increase in noise and behavioural or sleep outcomes. Continuation ratio models (Scott et al., 1997) were used for the ordinal behavioural outcomes which model the probability of being classified worse than a certain category given that one is classified at least in this category. Logistic regression models were used for the binary sleep outcomes. Adjusted models included the variables sex, age, study, parental educational level, mother's age at birth, television/computer usage and single parent status. Analyses on sleeping problems in the subgroup of children from LISAplus ($N=287$) were further adjusted for sleeping alone and for the direction of the child's bedroom window. The results are either presented as continuation odds ratios (cOR) for the continuation ratio models or as odds ratios (OR) for the logistic regression models with corresponding 95% confidence intervals (CI). The assumption of homogeneity across cutpoints of the ordinal behavioural outcomes for the exposure variable of interest (noise variable) was tested by performing a likelihood ratio test. For models with cutpoint-specific effects (p-value < 0.05) in either the crude or adjusted model the cOR for each cutpoint is stated. Pearson correlation coefficient with 95% CI was used to determine the correlation between the approximately normally distributed noise variables. All statistical analyses were carried out using the statistical software R, version 2.10.1 (〈http://www.r-project.org/〉, R Development Core Team, 2009). Continuation ratio models were fitted using the function vglm, R Package VGAM (Yee, 2010).

3. Results

3.1. Characteristics of the study population

The study population ($N=872$) consists of 583 children of the GINIplus cohort and 289 children of the LISAplus cohort. Table 1 shows the characteristics of the study population. In Table 2, the prevalence of behavioural problems measured by the SDQ problem scales and the total difficulties score in the complete study population as well as the prevalence of sleeping problems in the LISAplus subgroup are shown. The lowest and highest prevalence of borderline or abnormal scores on the behavioural problems scales was observed for peer relationship problems (8.4%) and emotional symptoms (18.1%), respectively. Of the 37 children with sleeping problems, 24 were reported to have only difficulties to fall asleep, four were reported to have only difficulties sleeping through the night, eight were reported to have both of the aforementioned sleeping problems and for one child the sleeping problems were not further specified.

Mean, standard deviation, range and IQR of the four road traffic noise variables are listed in Table 3. Noise is measured on a logarithmic scale. Effect sizes in the statistical models are provided per IQR-increase that ranged between 8.22 dB(A) and 9.02 dB(A). In terms of road traffic noise, an increase of 3 dB(A) would correspond to approximately a doubling of the traffic volume, an increase of 10 dB(A) to around a ten times higher traffic volume. The noise variables are very highly correlated: Correlation between noise levels at the most exposed façade (max(L_{den}) and max(L_{night})) was $r=0.995$ (95% CI: 0.994–0.997) and noise levels at the least exposed façade (min(L_{den}) and min(L_{night})) show a correlation of $r=0.994$ (95% CI: 0.993–0.995). Day–evening–night noise levels at the most exposed façade were between 5.0 and 11.2 dB(A) higher than levels measured at night. At the least exposed façade L_{den} was between 5.0 and 10.5 dB(A) higher than L_{night}. Noise levels at the most and least exposed façade of the same building were also highly correlated: $r=0.606$ (95% CI: 0.562–0.647) for night noise and $r=0.614$ (95% CI: 0.571–0.653) for noise during the whole day. The differences range between zero (only a single façade point noise level available for the address) and 32.5 dB(A) for L_{den} (32.1 dB(A) for L_{night}).

Table 1
Characteristics of the study population originating from the Munich subgroups of the GINIplus and LISAplus studies ($N=872$).

	n **(%) or mean ± standard deviation**[a]	
Study		
GINIplus-observational group	314	(36.0)
GINIplus-interventional group	269	(30.9)
LISAplus	289	(33.1)
Sex		
Female	410	(47.0)
Male	462	(53.0)
Age		
Years	10.1 ± 0.22	
Parental educational level[b]		
Low	46	(5.5)
Medium	138	(16.6)
High	650	(77.9)
Mother's age at birth[c]		
Young	206	(23.6)
Average	470	(53.9)
Old	196	(22.5)
Single parent status		
No	736	(86.1)
Yes	119	(13.9)
Television/computer usage[d]		
Low	636	(74.1)
High	222	(25.9)
Sleeping alone[e]		
Yes	229	(80.6)
No	55	(19.4)
Direction of child's room window[e]		
Not to street	175	(61.4)
To street	110	(38.6)

[a] Number of children in each category (n) for whom information on the variable is available and corresponding percentage (%), the sum of children with available information may be different from 872 due to missing data.
[b] Definition based on highest parental educational level: both parents with less than 10 years of schooling (low), at least one parent with 10 years of schooling (medium), at least one parent with more than 10 years of schooling (high).
[c] Categorisation based on 25th and 75th percentiles (30 and 35 years).
[d] "Low" is defined as 1 h or less per day in summer and 2 h or less per day in winter spent in front of a screen.
[e] Information on these variables is only available for children of the LISAplus study.

3.2. Noise levels and children's behavioural problems

Table 4 shows the results of the analyses on the association between road traffic noise exposure at home and children's behavioural problems measured by the SDQ. We observed that higher noise levels at the most exposed façade were associated with significantly more hyperactivity/inattention symptoms. The cORs per IQR-increase in noise levels in the models adjusted for study, sex, child's age, parental educational level, mother's age at birth, television/computer usage and single parent status were 1.28 (95% CI: 1.03–1.58) for max(L_{den}) and 1.32 (95% CI: 1.06–1.64) for max(L_{night}). Higher noise levels at the least exposed façade increased

Table 2
Characteristics of health outcome variables: behavioural problems assessed by the Strengths and Difficulties Questionnaire (SDQ) and sleep disturbance.

	n	(%)
SDQ[a]		
Total difficulties score		
Normal	740	(84.8)
Borderline	66	(7.6)
Abnormal	66	(7.6)
Emotional symptoms		
Normal	714	(81.9)
Borderline	65	(7.4)
Abnormal	93	(10.7)
Conduct problems		
Normal	758	(86.9)
Borderline	75	(8.6)
Abnormal	39	(4.5)
Hyperactivity/inattention		
Normal	765	(87.7)
Borderline	44	(5.1)
Abnormal	63	(7.2)
Peer relationship problems		
Normal	799	(91.6)
Borderline	37	(4.3)
Abnormal	36	(4.1)
Sleep disturbance[b]		
Any sleeping problems		
No	250	(87.1)
Yes	37	(12.9)
Problems to fall asleep		
No	254	(88.8)
Yes	32	(11.2)
Problems sleeping through the night		
No	274	(95.8)
Yes	12	(4.2)

[a] Categorisation of SDQ scores into "normal", "borderline", "abnormal" is based on cutoff points recommended for German samples (Woerner et al., 2004).
[b] Information on these variables is only available for children of the LISAplus study.

Table 3
Characteristics of road traffic noise variables (L_{den}[a] and L_{night}[b]) assessed at the most and least exposed façade of the children's home address.

	Mean ± standard deviation	**Range**	**Interquartile range**
$\boldsymbol{L_{den}}$ **in dB(A)**			
Most exposed façade	52.42 ± 7.87	35.40–74.70	9.00
Least exposed façade	44.92 ± 6.15	24.20–64.50	8.22
$\boldsymbol{L_{night}}$ **in dB(A)**			
Most exposed façade	43.36 ± 7.63	26.90–65.70	9.02
Least exposed façade	35.96 ± 6.27	15.40–55.40	8.52

[a] Day–evening–night equivalent noise level.
[b] Night equivalent noise level.

the relative odds for having borderline or abnormal values on the emotional symptoms scale (L_{den}: cOR = 1.18 (95% CI: 0.92–1.51); L_{night}: cOR = 1.19 (95% CI: 0.93–1.54)), especially the relative odds to have abnormal values on the emotional symptoms scale for a subject with at least borderline values (L_{den}: cOR = 2.19 (95% CI: 1.32–3.64); L_{night}: cOR = 2.29 (95% CI: 1.36–3.85)).

All four road traffic noise variables were associated with an increased, though not significant, risk for overall mental health problems measured by the total difficulties score.

3.3. Night noise levels and children's sleeping problems

In Table 5 the results of the analyses on the association between night noise levels at home and children's sleeping problems are summarised. We observed no significant associations between nocturnal noise levels at the most exposed façade and sleeping problems, neither in crude nor in any of the adjusted analyses. Higher noise levels at the least exposed façade were significantly associated with having any sleeping problems and with difficulties to fall asleep in crude analyses and also after adjustment for sex, child's age, parental educational level, mother's age at birth, television/computer usage and single parent status. The ORs increased after further adjustment for sleeping alone and for the orientation of the child's room window. In the full adjusted models an IQR-increase in L_{night} at the least exposed façade (min (L_{night})) was associated with a 79% (95% CI: 1.10–2.92) higher chance for having any sleeping problems and a 96% (95% CI: 1.16–3.32) higher chance for having problems to fall asleep.

In a sensitivity analysis, we observed that the presence of any sleeping problems was associated with more emotional symptoms (cOR = 3.07(95% CI: 1.60–5.90)). In this subgroup, higher noise levels at the least exposed façade were associated with an increased, but non-significant, risk for emotional symptoms. After additional adjustment for any sleeping problems the cOR was reduced by 10%.

4. Discussion

4.1. Main findings

Four main findings result from our analyses on road traffic noise exposure at home and children's behavioural problems and sleep disturbance. First, noise exposure at home was not associated with overall mental health problems measured by the total difficulties score. Second, higher levels of noise at the most exposed façade of the children's residential building were associated with a higher chance for higher scores on the hyperactivity/inattention scale of the SDQ. Third, children living at homes with higher noise levels at the least exposed façade were reported to have more emotional symptoms. Fourth, in a subgroup, we observed that night noise at the least exposed façade was associated with having any sleeping problems and especially with problems to fall asleep, also after adjustment for the direction of the child's room window.

4.2. Comparison with previous studies and interpretation of findings

Prevalences of behavioural problems assessed by the SDQ are similar to the prevalences obtained in the German norm population used for determining the national cutoffs (Woerner et al., 2002, 2004) and also similar to results obtained in a nationwide representative sample of German children and adolescents (Hölling et al., 2008).

In our study, residential road traffic noise exposure either assessed by L_{den} or by L_{night} was not related to overall mental health. In preceding studies, children's exposure to road traffic noise at school was also unrelated to the overall SDQ (Crombie et al., 2011; Stansfeld et al., 2005, 2009). Lercher et al. (2002) who investigated the effects of residential exposure to ambient daytime and nighttime noise (highway, rail and road) reported slightly lower values for children's self reported mental health, but only in children who were born preterm or had a low birth weight. As a birth weight below 2500 g or a gestational age less than 37 weeks were exclusion criteria for the GINIplus and

LISAplus studies, we were unable to investigate whether children not meeting these criteria would show an increased risk for overall mental health problems when exposed to higher levels of road traffic noise at home.

We observed that children living at homes with higher road traffic noise levels at the most exposed façade were reported to have more hyperactivity/inattention problems. Investigating children's exposure to road traffic noise at school, Stansfeld et al.

Table 4
Association between road traffic noise variables (L_{den}[a] and L_{night}[b]) at most and least exposed façade of the children's home address and behavioural problems assessed by the Strengths and Difficulties Questionnaire (SDQ) using continuation ratio models.

	Crude continuation odds ratio[c] (95% confidence interval)[d]	**Adjusted[e] continuation odds ratio[c] (95% confidence interval)[d]**
L_{den} at most exposed façade		
Total difficulties score (65;57/805)[f]	1.17 (0.97–1.40)	1.16 (0.95–1.40)
Emotional symptoms (58;84/805)	1.14 (0.96–1.35)	1.14 (0.95–1.37)
Conduct problems (69;35/805)	0.98 (0.80–1.20)	0.95 (0.76–1.18)
Hyperactivity/inattention (42;55/805)	1.29 (1.06–1.57)	1.28 (1.03–1.58)
Peer relationship problems (34;34/805)	0.95 (0.74–1.21)	0.93 (0.72–1.21)
L_{den} at least exposed façade		
Total difficulties score (65;57/805)	1.13 (0.91–1.40)	1.16 (0.91–1.46)
Emotional symptoms (58;84/805)	–	–
"Borderline/abnormal" vs. "normal"	1.15 (0.91–1.45)	1.18 (0.92–1.51)
"Abnormal" vs. "borderline"	1.89 (1.19–2.99)	2.19 (1.32-3.64)
Conduct problems (69;35/805)	0.95 (0.75–1.20)	0.93 (0.72-1.20)
Hyperactivity/inattention (42;55/805)	1.22 (0.95–1.55)	1.18 (0.91–1.52)
Peer relationship problems (34;34/805)	0.93 (0.70–1.24)	0.94 (0.70–1.28)
L_{night} at most exposed façade		
Total difficulties score (65;57/805)	1.19 (0.99–1.43)	1.18 (0.97–1.44)
Emotional symptoms (58;84/805)	1.16 (0.97–1.38)	1.17 (0.97–1.41)
Conduct problems (69;35/805)	0.99 (0.80–1.21)	0.95 (0.76–1.19)
Hyperactivity/inattention (42;55/805)	1.32 (1.08–1.62)	1.32 (1.06–1.64)
Peer relationship problems (34;34/805)	0.94 (0.73–1.21)	0.92 (0.70–1.21)
L_{night} at least exposed façade		
Total difficulties score (65;57/805)	1.14 (0.91–1.42)	1.17 (0.92–1.48)
Emotional symptoms (58;84/805)	–	–
"Borderline/abnormal" vs. "normal"	1.16 (0.91–1.46)	1.19 (0.93–1.54)
"Abnormal" vs. "borderline"	1.97 (1.23–3.15)	2.29 (1.36–3.85)
Conduct problems (69;35/805)	0.95 (0.75–1.21)	0.93 (0.72–1.20)
Hyperactivity/inattention (42;55/805)	1.23 (0.96–1.57)	1.19 (0.92–1.55)
Peer relationship problems (34;34/805)	–	–
"Borderline/abnormal" vs. "normal"	1.04 (0.75–1.45)	1.08 (0.77–1.53)
"Abnormal" vs. "borderline"	0.55 (0.28–1.07)	0.49 (0.24–1.00)

[a] Day-evening-night equivalent noise level.
[b] Night equivalent noise level.
[c] The reported continuation odds ratios are homogeneous across the cutoffs of the ordinal SDQ variables (in case either the crude or the adjusted model violated this assumption, cutpoint-specific effects are reported).
[d] Effects per interquartile range increase in noise levels.
[e] Adjusted for study, sex, child's age, parental educational level, mother's age at birth, television/computer usage and single parent status.
[f] (n_{bord}; n_{abn}/N): number of cases (n_{bord}=number of children classified as borderline; n_{abn}=number of children classified as abnormal) out of all samples (N) used for adjusted model.

Table 5
Association between nocturnal road traffic noise (L_{night}[a]) at most and least exposed façade of the children's home address and sleep disturbance using logistic regression models.

	Crude odds ratio (95% confidence interval)[b]	**Adjusted I[c] odds ratio (95% confidence interval)[b]**	**Adjusted II[d] odds ratio (95% confidence interval)[b]**	**Adjusted III[e] odds ratio (95% confidence interval)[b]**
L_{night} at most exposed façade				
Any sleeping problems (31/271)[f]	1.16 (0.78–1.72)	1.14 (0.76–1.71)	1.14 (0.75–1.74)	1.23 (0.80–1.91)
Problems to fall asleep (26/270)	1.12 (0.74–1.70)	1.09 (0.71–1.68)	1.08 (0.69–1.70)	1.18 (0.74–1.88)
Problems sleeping through the night (8/270)	1.26 (0.67–2.40)	1.03 (0.52–2.07)	0.92 (0.42–2.03)	0.95 (0.38–2.35)
L_{night} at least exposed façade				
Any sleeping problems (31/271)	1.66 (1.07–2.56)	1.68 (1.07–2.63)	1.72 (1.08–2.75)	1.79 (1.10–2.92)
Problems to fall asleep (26/270)	1.75 (1.10–2.79)	1.83 (1.13–2.97)	1.85 (1.11–3.08)	1.96 (1.16–3.32)
Problems sleeping through the night (8/270)	1.25 (0.62–2.54)	1.06 (0.53–2.14)	0.98 (0.45–2.14)	0.90 (0.38–2.13)

[a] Night equivalent noise level.
[b] Effects per interquartile range increase in noise levels.
[c] Adjusted for sex, child's age, parental educational level, mother's age at birth, television/computer usage and single parent status.
[d] Model adjusted I further adjusted for sleeping alone.
[e] Full model: model adjusted II further adjusted for the direction of the child's room window.
[f] (n/N): number of cases (n) out of all samples (N) used for full model.

(2009) and Crombie et al. (2011) did not observe an association with SDQ hyperactivity/inattention in the RANCH study population. An explanation for this may be that the duration of exposure is relevant. German children at the age of 10 years mainly attend half-day schools. In a representative survey of German children, Conrad et al. (2013) reported, that children aged 9–11 spend on average slightly more than 15 h per day at home. The time spent at home is thus considerably higher than the time spent at school. Road traffic noise exposure at home may be a better marker for overall exposure than exposure at school and therefore be related to more adverse effects on hyperactivity in children. Unfortunately, we could not compare the influence of home vs. school exposure in our study as information on noise exposure levels at the children's schools was unavailable. Previous studies on the effect of aircraft noise exposure at school reported an association with more hyperactivity symptoms (Haines et al., 2001a; Stansfeld et al., 2009; Crombie et al., 2011). However, different sources of transportation noise (aircraft or road traffic) have different acoustical characteristics. For example, aircraft noise is more intense and has a higher variability compared to road traffic noise which, at daytime, has a tendency to a rather constant intensity (Hygge, 2003; Stansfeld et al., 2005) and is more intermittent at nighttime (Pirrera et al., 2010). Thus, comparison of effects of differing noise sources is difficult.

It has been proposed that health is impaired by prolonged noise exposure either via increased annoyance and/or directly via chronically augmented arousal levels (Babisch, 2002; WHO, 2009). Especially children with hyperactivity or inattention problems who are easily distracted, could be more sensitive to external noise stimuli (Clark and Stansfeld, 2007; Stansfeld et al., 2009). It is hypothesised that exposure to noise may worsen already existent mild hyperactivity symptoms which then lead to high scores on the hyperactivity/inattention scale (Stansfeld et al., 2009).

In our data, we observed a significant association of road traffic noise levels at the least exposed façade of the children's homes with more emotional symptoms. To the best of our knowledge, to date no study has yet investigated the effects of road traffic noise at home specifically on emotional symptoms in children. Daytime road traffic noise at school was reported to be unrelated to emotional symptoms (Stansfeld et al., 2009; Crombie et al., 2011). As explanation for the contrasting results compared to our results we mention again that road traffic noise at home may have a bigger impact on emotional problems due to the longer exposure time than exposure at school. Moreover, noise exposure at night may be more harmful than daytime noise exposure. At night, the organism needs to rest and disrupted sleep has adverse effects on well-being and health (WHO, 2009). In the LISAplus subgroup of the study population, we observed that nocturnal noise at the least exposed façade was associated with sleeping problems and that the presence of any sleeping problems was associated with more emotional symptoms. Sleeping problems and emotional difficulties in children have been reported to be associated and the association is likely to be bidirectional (Gregory and Sadeh, 2012; WHO, 2009). After adjustment for sleeping problems, the association between nighttime noise and emotional symptoms was attenuated. This leads us to the speculation that continued exposure to higher noise levels at night could lead to sleeping problems which, in turn, are related to an increased risk for having emotional symptoms. It is also possible that emotional symptoms lead to sleeping problems which are further deteriorated by exposure to nighttime noise. Our observation that noise, in particular, plays a role in the transition from borderline to abnormal values on the emotional symptoms scale seems to support this hypothesis.

Nighttime noise has been associated with negative effects on sleep such as difficulties falling asleep, a higher number of nocturnal awakenings and decreased sleep quality (Pirrera et al., 2010; WHO, 2009). As presumed, we observed an effect of nighttime noise on sleeping problems and especially problems to fall asleep. However, these associations were only observed when we defined the exposure by the noise levels at the least exposed façade of the child's home and not by the levels at the most exposed façade. An explanation for this finding may be that bedrooms are mainly facing the quieter façade of the dwelling and that min(L_{night}) is a better proxy for the true noise levels outdoors at the bedroom façade of the child than max(L_{night}). A previous cross-sectional study in 160 9–12-year-old children on nocturnal road traffic noise exposure and sleeping problems found a moderate, significant exposure-response relationship between noise and sleep quality and problems with sleepiness during daytime but no significant association with difficulties falling asleep (Öhrström et al., 2006).

4.3. Strengths and limitations

Strengths of our study include the availability of a series of potential confounders to control for their influence on the association between noise exposure and child behavioural problems and sleep disturbance. Furthermore, noise exposure was not only assessed by the weighted day–evening–night noise indicator but also by the night noise indicator which were both derived from a validated noise model meeting the requirements of the European Noise Directive (Directive 2002/49/EC, 2002). The time of assessment of behavioural outcomes and sleeping problems was around the year 2007 for which the Munich noise map was created. More than 95% (837 of 872) of the questionnaires were filled in between 2006 and 2008.

However, we also need to state several limitations. Our first limitation refers to the fact that we do not have detailed information on where exactly the apartment of the study child's family is located in an apartment house. The noise levels at the most or least exposed façade of the building do not necessarily need to reflect the maximum and minimum noise levels outside of the apartment in which the child lives. Thus, an over- or underestimation of noise levels is possible. This is not a problem for children living in a single-family house. In the analysis on noise and sleeping problems which was conducted in the subgroup of children from the LISAplus study, we tried to account for this issue by adjusting for the information whether the child's bedroom window is facing the street or not. However, even in this case a misclassification is possible when the parents indicate that the child's bedroom window is facing the street next to the house, but the most exposed façade is not the one exposed to the street next to the house but to another noisier street nearby. Furthermore, noise levels were modelled 4 m above ground level and therefore correspond mainly to the noise exposure of the lower floors of a building. Children living at upper floors are likely to have different exposure levels. A further limitation is related to the discrepancy between the true inside noise exposure at home of the children in the study and the modelled noise exposure variables used within this study, namely façade levels at the home address. The noise levels inside the apartments depend on noise insulation characteristics and on ventilation behaviour. Unfortunately, such data was not available in our study. Another limitation is related to the measurement error of the noise variables. In general, the measurement error increases from high to lower sound levels due to less accurate input data, and may be higher on the least exposed side of the house than on the most exposed side of the house due to the stronger impact of multiple reflections and related absorption factors of façades. It is difficult to quantify the magnitude of the measurement error in each individual case. However, it seems likely that bias, if it occurred, is in the direction of an underestimation of the true risk, because the true noise exposure may be higher than calculated-thus diminishing the exposure contrast and the effect size. Moreover, we need to mention that the 8 h of night–time included for the calculation of the night noise indicator L_{night} (10 p.m.–6 a.m.) may not entirely cover the sleeping period of the children in our study. Parent-reported sleep duration in the LISAplus subgroup of the children studied was mainly between nine and ten hours. An underestimation of the noise levels at the time the children fall asleep or at the end of their sleeping period is possible. However, we suppose that evening or early morning noise levels are highly correlated with night noise levels with slightly lower noise levels during the night. We also need to mention that behavioural problems were assessed by a screening questionnaire filled in by the parents and could not be ascertained by a physician's diagnosis. We only had parent-reported sleeping problems available instead of an objective measurement for example by actigraphy or assessment by self-reported sleep quality using a standard questionnaire which leads us to interpret results for this analysis with caution. Another limitation refers to the fact that we were not able to include information on parental psychopathology which may be a source of residual confounding. Furthermore, even if we carefully adjusted our analyses for variables related to socioeconomic status (parental educational level and single parent status) we cannot completely rule out a potential bias. The results obtained in a sensitivity analysis with adjustment for net equivalent income instead of single parent status were similar. Due to a high correlation of the variables income and single parent status a simultaneous inclusion of both variables in the models was not possible. Finally, as this is a cross-sectional study, causal relationships cannot be inferred.

5. Conclusions

Our data indicate that children's exposure to road traffic noise at home may be related to increased hyperactivity. Moreover, we observed more emotional symptoms especially in children exposed to higher nocturnal noise. However, this association may be confounded by the presence of sleeping problems. More longitudinal studies are required to explore the temporal sequence of noise exposure, sleep disturbances and behavioural problems.

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Ethical approval

The GINIplus and LISAplus studies were approved by the local ethics committees.

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