Association between Ambient Noise Exposure and School Performance of Children Living in An Urban Area: A Cross-Sectional Population-Based Study

Sophie Pujol, Jean-Pierre Levain, Hélène Houot, Rémy Petit, Marc Berthillier, Jérôme Defrance, Joseph Lardies, Cyril Masselot, et al.

Journal of Urban Health
Bulletin of the New York Academy of Medicine

ISSN 1099-3460

J Urban Health
DOI 10.1007/s11524-013-9843-6

Springer

Journal of Urban Health: Bulletin of the New York Academy of Medicine
doi:10.1007/s11524-013-9843-6

Association between Ambient Noise Exposure and School Performance of Children Living in An Urban Area: A Cross-Sectional Population-Based Study

Sophie Pujol, Jean-Pierre Levain, Hélène Houot, Rémy Petit, Marc Berthillier, Jérôme Defrance, Joseph Lardies, Cyril Masselot, and Frédéric Mauny

ABSTRACT *Most of the studies investigating the effects of the external noise on children's school performance have concerned pupils in schools exposed to high levels due to aircraft or freeway traffic noise. However, little is known about the consequences of the chronic ambient noise exposure at a level commonly encountered in residential urban areas. This study aimed to assess the relationship between the school performance of 8- to 9-year-old-children living in an urban environment and their chronic ambient noise exposure at home and at school. The children's school performances on the national standardized assessment test in French and mathematics were compared with the environmental noise levels. Children's exposure to ambient noise was calculated in front of their bedrooms (L_{den}) and schools ($L_{Aeq,day}$) using noise prediction modeling. Questionnaires were distributed to the families to collect potential confounding factors. Among the 746 respondent children, 586 were included in multilevel analyses. On average, the $L_{Aeq,day}$ at school was 51.5 dB (SD=4.5 dB; range=38–58 dB) and the outdoor L_{den} at home was 56.4 dB (SD=4.4 dB; range=44–69 dB). $L_{Aeq,day}$ at school was associated with impaired mathematics score ($p=0.02$) or impaired French score ($p=0.01$). For a+10 dB gap, the French and mathematics scores were on average lower by about 5.5 points. L_{den} at home was significantly associated with impaired French performance when considered alone ($p<10^{-3}$) and was borderline significant when the combined home-school exposure was considered ($p=0.06$). The magnitude of the observed effect on school performance may appear modest, but should be considered in light of the number of people who are potentially chronically exposed to similar environmental noise levels.*

KEYWORDS *Environmental noise exposure, Ambient noise, Children, School performance, Urban area*

Pujol and Mauny are with the Chrono-environnement laboratory, UMR 6249 CNRS/Université de Franche-Comté, Besançon, France; Levain is with the Laboratory of Psychology, EA 3188, IUFM de l'Université de Franche-Comté, Besançon, France; Houot is with the ThéMA laboratory, UMR 6049 CNRS/Université de Franche-Comté, Besançon, France; Petit is with the Education authority Inspection académique du Doubs, Besançon, France; Berthillier and Lardies are with the FEMTO-ST Institut, UMR 6174 CNRS/Université de Franche-Comté, DMA, Besançon, France; Defrance is with the Building research center Centre scientifique et technique du bâtiment, Saint-Martin-d'Hères, France; Masselot is with the CIMEOS EA 4177/Université de Bourgogne, Dijon, France; Pujol and Mauny are with the CMC, Regional Universitary Hospital of Besançon (CHRU de Besançon), 2 place Saint Jacques, 25030 Besançon Cedex, France.

Correspondence: Frédéric Mauny, CMC, Regional Universitary Hospital of Besançon (CHRU de Besançon), 2 place Saint Jacques, 25030 Besançon Cedex, France. (E-mail: frederic.mauny@univ-fcomte.fr)

Professor Marc Berthillier died between the submission and the acceptance of this article.

Published online: 05 November 2013

INTRODUCTION

Environmental noise from roads, rails, airports, and industrial sites is known to have negative impacts on human health and well-being, including cardiovascular disease, sleep disturbance, annoyance, and cognitive impairments.[1–4] In the past 30 years, many investigations have examined the effects of noise on the learning and performance of children at school.[5] There is growing scientific evidence that elevated noise levels and prolonged noise exposures impair cognition, particularly attention, reading, memory, learning, and problem-solving.[6] Several pathways have been proposed to explain the cognitive effects of noise exposure: reduction of speech intelligibility,[5] impaired attention (gate out distraction),[6] indiscriminate filtering out of noise,[7] annoyance,[8] and indirect effects mediated by sleep disturbance.[1] Most of the published work on the effects of external noise has concerned pupils in schools exposed to noise due to aircraft[9–15] or freeway traffic.[16–18]

People living in urban areas are typically surrounded by a mixture of sounds associated with humans and their activities.[19] According to the European Environmental Agency, road traffic is by far the main source of exposure to transportation noise in Europe.[20] The non-auditory consequences of typical ambient noise exposure on children have already been highlighted, including stress,[21] mental health effects,[22] and neurobehavioral effects.[23] However, very few studies have been conducted on the effects of the chronic ambient noise exposure on the cognitive processes or school performance of children at a level that is common in residential areas. Lercher et al.[24] observed worse memory when comparing two groups of children chronically exposed to ambient noise at home (road and rail traffic, 46 vs. 62 dB L_{dn}). Shield and Dockrell[25] identified negative correlations between noise at school (mainly road traffic noise in the range of 49–75 dB $L_{Aeq,5min}$) and the children's academic performance in literacy, mathematics, and science. The results of these studies are not sufficient to establish an exposure–effect relationship between the chronic combined exposure to noise that occurs in a residential area at home and at school and the cognitive performance of children.

The aim of this study was to assess the relationship between typical ambient noise exposure at home and at school and the school performance of 8- to 9-year-old children living in an urban environment.

METHODS

Population

The participants were all the 8- and 9-year-old schoolchildren living in the city of Besançon (France) and attending one of the 35 public primary schools of the city in key stage 2, year 4 in 2006–2007. Pupils who changed residences after the start of the last school year and hearing-impaired children were not included in this study.

Assessment of Potential Confounding Factors

The families were given written consent forms and standardized questionnaires.[26] The collected data included the household socio-economic characteristics (single parenthood and parental occupation, employment status (whether the parents worked full or part-time), and educational level); family size; the number of residents; residency duration; the child's age, sex, and birth order; main language spoken at home; and dwelling characteristics (address, floor level, type of dwelling, type of built neighborhood, number of rooms, type of windows, view from the

child's bedroom window, and name of the street in front of the child's bedroom). The distribution and collection of the questionnaires among the families were handled by the teachers. Help was proposed by the school for families who did not speak the main language at home.

School Performance Assessment

Since 1989, national standardized assessment tests have been used in France to evaluate the knowledge that pupils in key stage 2, year 4 have in French and mathematics. These tests are designed to provide information on the pupils' knowledge, skills, and gaps, with the objective of assisting teachers in adapting their pedagogy to the needs of their students. In each French public primary school, French and mathematics tests were administered in the classrooms by the teacher under exam conditions, according to a national schedule, in September 2006. For each subject, three tests were given in a fixed order in 30-minute periods over 6 half-days. The French test was composed of 93 items that consider reading comprehension, word recognition, writing, handwriting, and spelling at the individual level. The mathematics test was composed of 88 items that evaluate solid geometry, problem-solving, size and measurement, number knowledge, and calculations. In each school, the tests were corrected by the teacher. The results obtained for each item in each subject were expressed as the total score out of 100. The total French score and the total mathematics score were selected for analysis.

Noise Exposure Assessment

Noise exposure was assessed using a strategic noise map developed by Pujol et al.,[27] in accordance with the European Commission's Environmental Noise Directive 2002/49/CE,[28] using the noise prediction software MITHRA.[29] The data collected by the standardized questionnaire were used to precisely locate the child's dwelling (address, floor, and type of dwelling) and the child's bedroom façade (view from the child's bedroom, name of the street in front of this window). Four noise indicators based on the outdoor equivalent continuous A-weighted sound levels (L_{Aeq}, in dB) were calculated in front of each façade of the child's home and in front of the school: the $L_{Aeq,day}$ (06:00–18:00), $L_{Aeq,evening}$ (18:00–22:00), $L_{Aeq,night}$ (22:00–06:00), and the L_{den} (defined as the A-weighted 24-h equivalent continuous sound level, with an addition of 5 dB for $L_{Aeq,evening}$ and 10 dB for $L_{Aeq,night}$), according to the European Commission.[28] The school average outdoor $L_{Aeq,day}$ (calculated in front of each façade and each floor) and the outdoor L_{den} calculated in front of the child's bedroom were selected for analysis. When it was not possible to precisely determine the location of the child's bedroom façade, all of the facades were considered, and the noise levels were averaged.

Data Processing

Four socio-economic status classes were determined using the parental occupations, according to the French National Institute of Statistics and Economic Studies (INSEE) classification,[30] as follows: socio-economic status (SES)-1 = working class or unemployed; SES-2 = non-managerial position/clerk; SES-3 = middle class job/mid-management position; and SES-4 = senior management position/artisan, shopkeeper, and entrepreneur/corporate manager. The socio-economic status of the household was considered based on the class of the more privileged member of the couple. The parent's employment status was used to define if there was at least one full-time worker in the family (one parent was a full-timer, or the two parents were part-

timers). Overcrowding was defined as a number of people per room higher than one. Single-glazed windows and extra-glazed windows were considered to be single-glazed windows, whereas both double-glazed windows and double windows were considered to be double-glazed windows. The age of the child was used to determine if the child was older than expected (i.e., older than 8 years old as of December 31, 2006).

Statistical Analysis

Descriptive statistics are presented as the means and standard deviations (SD) or as percentages (%). The association between numeric variables was assessed using the Pearson correlation. To take into account the hierarchical structure of the data, with pupils being members of a school, multilevel linear regression models[31] were performed to assess the relation between the school performances and the outdoor L_{den} at home and $L_{Aeq,day}$ at school and confounding factors. Sensitivity analyses were performed using $L_{Aeq,day}$, $L_{Aeq,evening}$, or $L_{Aeq,night}$ at home instead of L_{den}. A missing value category was assigned to subjects for whom no values for the potential confounding factor(s) were available. The variables that were associated with the school performance at p value (p) ≤ 0.20 in the univariate analysis were then included in the multivariate analysis using a backward step-by-step elimination procedure. Departure from the linearity assumption was tested by introducing a polynomial function of the centered variables into the models, especially when considering the school and home noise exposures. The percentage of the variance explained by a model was calculated using random effect variances of the "null" model (containing only an intercept term) and those of the considered model. The threshold considered for statistical significance was $p = 0.05$. Two software programs were used to perform the analyses: SYSTAT 12.02 (SYSTAT Software, Inc., Chicago, IL) and MLwiN 2.24 (University of Bristol, UK).[32]

Ethics

This study was approved by the French National Advisory Committee for the Treatment of Information in Health Research (CCTIRS) and the French National Computing and Freedom Committee (CNIL).

RESULTS

From among the 964 pupils attending the public primary schools of the city in key stage 2, year 4 in 2006–2007, 746 children replied to the questionnaire (response rate = 77.4 %; Fig. 1). Considering the 667 pupils meeting the selection criteria, school performance was available for 587 pupils in the French test and for 586 pupils in the mathematics test. The school performances of 4 schools were not available (51 pupils).

Child, Family, and Dwelling Characteristics

The main characteristics of the study children, their families, and their dwellings are presented in Table 1. The pupils averaged 8.2 years old (SD = 0.5, range = 7–12 years old, $n = 534$), 53.2 % were boys, and 16.5 % were older than expected. Approximately 65 % of the children declared reading as a leisure activity. Most of children lived with their two parents at home (68.3 %), 23.5 % lived in a single-parent family, and 4.5 % lived in a reconstituted family. The average number of children per family was 2.8 (range 1–10). The average number of people per room

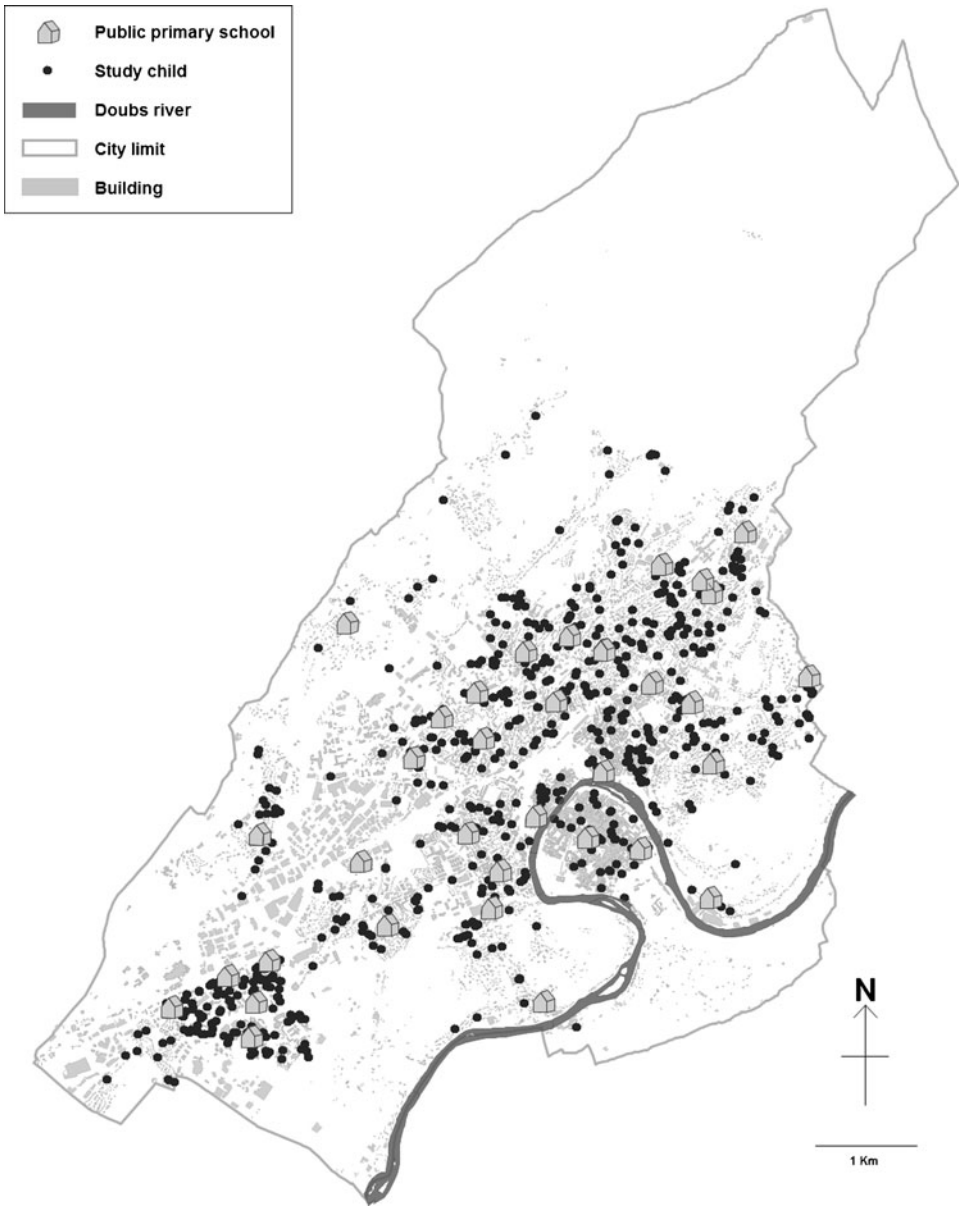

FIGURE 1. Spatial distribution of the studied children and the public primary schools in the city.

was 0.98; this number was higher than one in 27.7 % of the dwellings. French was the main language spoken at home in most of the families (92.5 %), and at least one full-time worker was present in 76.7 % of the families.

Noise Exposure

At home, the outdoor L_{den} values in front of the child's bedroom and in front of the most exposed façade ranged between 44 and 69 dB (mean=56.4 dB; SD=4.4 dB) and between 47 and 69 dB (mean=59.2 dB; SD=4.0 dB), respectively (Fig. 2). The correlation coefficients between the L_{den} and $L_{Aeq,day}$, $L_{Aeq,evening}$, or $L_{Aeq,night}$ ranged between 0.97 and 0.99 in front of the child's bedroom (all $p<10^{-3}$). The

TABLE 1 Participant characteristics ($n=587$)

	n	%
Household characteristics		
Household socio-economic status[a] (missing values: 43)		
SES-1	57	10.5
SES-2	161	29.6
SES-3	148	27.2
SES-4	178	32.7
Maternal education (missing values: 54)		
Elementary school	13	2.4
Middle school	101	19.0
High school	187	35.1
University	232	43.5
Paternal education (missing values: 148)		
Elementary school	18	4.1
Middle school	83	18.9
High school	134	30.5
University	204	46.5
Parents' employment status (missing values: 7)		
No full-time worker	135	23.3
At least one full-time worker	445	76.7
Dwelling characteristics		
Type of dwelling (missing values: 6)		
Detached house	119	20.5
Semi-detached house	24	4.1
Apartment building (2–6 dwellings)	76	13.1
Apartment building (>6 dwellings)	349	60.1
Other	13	2.2
View from the child's window (missing values: 38)		
Courtyard	115	20.9
Grassy area	200	36.4
Low traffic street	120	21.9
Heavy traffic street	114	20.8
Type of window (missing values: 35)		
Single-glazed	124	22.5
Double-glazed	428	77.5

[a]SES-1=working class or unemployed; SES-2=non-managerial position/clerk; SES-3=middle class job/mid-management position; SES-4=senior management position/artisan, shopkeeper, and entrepreneur/corporate manager

correlation coefficients between the noise levels at home and at school ranged between 0.10 and 0.11 ($0.01<p<0.02$). At school, the average outdoor $L_{Aeq,day}$ ranged between 38 and 58 dB (mean=51.5 dB; SD=4.5 dB), and the most exposed façade $L_{Aeq,day}$ ranged between 41 and 69 dB (mean=56.7 dB; SD=6.5 dB).

School Performance

The mean scores in French and mathematics both reached 70 %. The achievement scores ranged between 12 % and 97 % in French and between 12 % and 100 % in mathematics. On average, the L_{den} at the homes of the pupils having already repeated a year (i.e., pupils older than 8 years old) was higher than the L_{den} at the homes of the other pupils (mean=58.2 dB; SD=4.7 dB vs. mean=56.2 dB; SD=4.2 dB, respectively, $p<10^{-3}$).

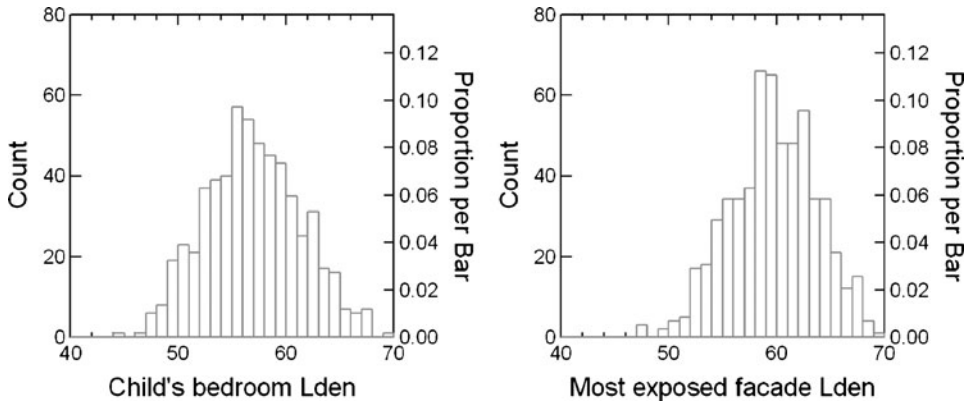

FIGURE 2. Noise exposure at home: outdoor L_{den} in front of the child's bedroom and in front of the most exposed facade.

Association between Noise and School Performance

The scores in French were found to be negatively associated with the L_{den} at home or the $L_{Aeq,day}$ at school ($p<10^{-3}$ and $p=0.04$, respectively) before adjustment for confounding factors (Table 2, models 1 and 2). This association remained significant or nearly significant when the L_{den} at home and $L_{Aeq,day}$ at school were simultaneously considered (model 3; $p<10^{-3}$ and $p=0.06$, respectively). After adjustment for confounding factors (sex, reading as a leisure activity, main language spoken at home, mother's education, household SES, and parents' employment status), the association between an impaired French score and the $L_{Aeq,day}$ at school became significant ($p=0.01$, model 4); it became nearly significant with the L_{den} at home ($p=0.06$, model 4). When the child's age was also included in the model (model 5), the $L_{Aeq,day}$ at school was still negatively associated with the French score ($p=0.02$), but the association with the L_{den} at home was no longer significant ($p=0.10$). Similar results were obtained when analyses were performed using $L_{Aeq,day}$, $L_{Aeq,evening}$, or $L_{Aeq,night}$ at home instead of L_{den} at home (data not shown). The parts of the variance explained by models 4 and 5 reached 28 % and 33 %, respectively, compared with 6 % when only the noise levels were considered.

The mathematics score was not associated with either the L_{den} at home or the $L_{Aeq,day}$ at school when considered alone ($p=0.15$ and $p=0.09$, respectively). When the L_{den} at home and $L_{Aeq,day}$ at school were simultaneously considered (Table 3), the L_{den} at home was borderline significantly associated with an impaired mathematics score before adjustment for confounding factors ($p=0.07$, model 6), but not after adjustment ($p\geq 0.50$, models 7 and 8). In contrast, the $L_{Aeq,day}$ at school, which was not associated with an impaired mathematics score in model 6 ($p=0.11$), became significantly associated after adjustment for confounding factors ($p \leq 0.04$, models 7 and 8). Similar results were obtained when analyses were performed using $L_{Aeq,day}$, $L_{Aeq,evening}$, or $L_{Aeq,night}$ at home instead of L_{den} at home (data not shown). The proportions of variance explained by models 7 and 8 reached 20 % and 26 %, respectively, compared with 3 % when only the noise levels were considered.

DISCUSSION

A linear exposure–effect relationship was identified between the ambient noise exposure at school and impaired French and mathematics test results. A borderline significant negative association between ambient noise exposure at home and the

TABLE 2 Multilevel models parameter estimates for ambient noise exposure and French scores (*n* pupils = 579*; *n* schools = 31)

	Model 1			Model 2			Model 3			Model 4			Model 5		
Independent variables	β	95 % CI	*p*	β	95 % CI	*p*	β	95 % CI	*p*	β	95 % CI	*p*	β	95 % CI	*p*
Intercept	69.25			68.8			68.98			56.37			57.88		
L_{den} at home (for 1-dB increase)	−0.45	−0.70 to −0.20	$<10^{-3}$				−0.44	−0.69 to −0.19	$<10^{-3}$	−0.23	−0.46 to 0.01	0.06	−0.19	−0.42 to 0.04	0.10
$L_{Aeq,day}$ at school (for 1-dB increase)				−0.63	−1.22 to 0.04	0.04	−0.58	−1.15 to 0.00	0.06	−0.56	−0.99 to −0.13	0.01	−0.48	−0.87 to −0.08	0.02
Sex															
Female										Ref			Ref		
Male										−3.43	−5.48 to −1.38	0.00	−3.01	−5.02 to −1.00	0.01
Age															
≤8 years old													Ref		
>8 years old													−8.32	−11.47 to −5.16	$<10^{-3}$
Missing value													3.88	−0.10 to 7.87	
Reading is a leisure activity															
Yes										Ref			Ref		
No										2.90	0.74 to 5.06	0.01	3.17	1.06 to 5.28	0.01
Main language spoken at home															
French										Ref			Ref		
Other language										−5.30	−9.44 to −1.16	0.01	−3.06	−7.17 to 1.05	0.15
Mother's education															
Elementary school										Ref			Ref		
Middle school										5.88	−1.28 to 13.03	$<10^{-3}$	5.14	−1.84 to 12.12	$<10^{-3}$
High school										9.63	2.59 to 16.67		7.68	0.78 to 14.58	
University										14.59	7.53 to 21.65		12.04	5.11 to 18.98	
Missing value										3.58	−3.88 to 11.03		2.81	−4.46 to 10.08	
Household socio-economic status															
SES-1										Ref			Ref		
SES-2										0.80	−2.96 to 4.55	0.44	1.68	−2.00 to 5.36	0.40
SES-3										2.15	−1.87 to 6.17		3.06	−0.87 to 6.99	
SES-4										2.41	−1.50 to 6.32		3.25	−0.57 to 7.08	

Missing value							−1.59	−6.93 to 3.75		0.27	−5.00 to 5.54	
Parents' employment status												
No full-time worker							Ref			Ref		
At least one full-time worker							2.02	−0.53 to 4.58	0.08	1.94	−0.56 to 4.44	0.08
Missing value							−7.37	−17.45 to 2.71		−7.16	−16.99 to 2.67	
Random parameters												
Level 2: school	53.07	16.17	48.84	15.11	46.42	14.46	22.94	8.02		18.69	6.82	
Level 1: pupil	169.90	10.26	173.15	10.46	169.85	10.26	142.84	8.63		135.98	8.21	
Percentage of the explained variance	3.1		3.6		6.0		28.0			32.8		

*Due to missing values (reading is a leisure activity: $n=7$; main language spoken at home: $n=3$). β = the estimated change in the French score; CI = confidence interval; $p = p$ value; SES-1 = working class or unemployed; SES-2 = non-managerial position/clerk; SES-3 = middle class job/mid-management position; SES-4 = senior management position/artisan, shopkeeper, and entrepreneur/corporate manager

TABLE 3 Multilevel models parameter estimates for ambient noise exposure and mathematics scores (*n* pupils=586; *n* schools=31)

	Model 6			Model 7			Model 8		
	β	95 % CI	*p*	β	95 % CI	*p*	β	95 % CI	*p*
Independent variables									
Intercept	69.83			53.87			56.89		
L_{den} at home (for 1-dB increase)	−0.22	−0.53 to 0.09	0.07	−0.10	−0.40 to 0.20	0.50	−0.03	−0.32 to 0.26	0.85
$L_{Aeq,day}$ at school (for 1-dB increase)	−0.53	−1.18 to 0.11	0.11	−0.55	−1.01 to −0.08	0.02	−0.44	−0.85 to −0.02	0.04
Sex									
Female				Ref			Ref		
Male				4.43	1.83 to 7.03	$<10^{-3}$	5.19	2.67 to 7.72	$<10^{-3}$
Age									
≤8 years old							Ref		
>8 years old							−10.83	−14.74 to −6.92	$<10^{-3}$
Missing value							6.85	1.84 to 11.86	
Mother's education									
Elementary school				Ref			Ref		
Middle school				5.29	−3.91 to 14.49	$<10^{-3}$	3.50	−5.43 to 12.44	$<10^{-3}$
High school				9.60	0.60 to 18.60		6.26	−2.55 to 15.06	
University				15.66	6.61 to 24.71		11.71	2.84 to 20.58	
Missing value				3.21	−6.37 to 12.79		2.00	−7.31 to 11.30	
Household socio-economic status									
SES-1				Ref			Ref		
SES-2				1.19	−3.64 to 6.01	0.15	2.09	−2.61 to 6.78	0.18
SES-3				1.16	−3.98 to 6.29		2.07	−2.92 to 7.05	
SES-4				2.49	−2.52 to 7.51		3.50	−1.37 to 8.38	
Missing value				−5.55	−12.34 to 1.24		−3.61	−10.25 to 3.03	
Parents' employment status									
No full-time worker				Ref			Ref		
At least one full-time worker				2.82	−0.45 to 6.10	0.14	2.77	−0.41 to 5.96	0.13
Missing value				7.97	−5.02 to 20.95		8.29	−4.30 to 20.87	

Random parameters						
Level 2: school	55.27	18.15	24.00	9.69	17.17	7.69
Level 1: pupil	266.08	15.97	241.07	14.46	227.50	13.64
Percentage of the explained variance	2.7		19.7		25.9	

β = the estimated change in the Mathematics score; CI = confidence interval; *p* = *p* value; SES-1 = working class or unemployed; SES-2 = non-managerial position/clerk; SES-3 = middle class job/mid-management position; SES-4 = senior management position/artisan, shopkeeper, and entrepreneur/corporate manager

child's performance was also highlighted in French, but not in mathematics. To our knowledge, this study is the first to simultaneously evaluate the effect of a typical ambient noise exposure at home and at school on the children's school achievement at noise levels typically occurring in a residential area.

Due to the involvement of the teachers and the assistance they proposed to the families, the participation rate in this study was high, including in schools from underprivileged areas. The study children were geographically distributed throughout the municipal area. The children were not pre-screened for normal hearing as in previous studies,[12,24] but at the time of school enrollment, no child was declared as having special needs with respect to a hearing impairment. To take into account the fact that the standardized assessment tests are based on the acquisition of knowledge during the prior school years and to ensure that the estimated exposure did not reflect a recent situation, only children who had not relocated residences since September 2005 were included in the analysis. Furthermore, long-term noise levels were calculated instead of short-term measurements that could be influenced by temporary events.

The results of the curriculum national standardized assessment test were used. These tests were administered simultaneously in all schools in a fixed order, alternating with rest periods or recreational activities according to the same national protocol, and were corrected using the same evaluation matrix, which guarantees the between-children and between-school comparability. The scores of the children participating in the study were similar to the average national scores (i.e., 69.7 in French and 69.9 in mathematics).[33] The teachers were not informed about the use of the results in the context of this study when the tests were administered. The children's school performances were assessed by the teacher in the classroom under exam conditions. Some studies have assessed children under quiet conditions to ensure that the observed effects of noise were due to chronic exposure rather than acute conditions during the testing phase.[6,12,24] Some authors have measured the indoor or outdoor noise level during tests to adjust for the noise level during the analysis.[8,9,14,15] Several studies have group-administered cognitive performance tests in the classroom,[8–10,13–15,18] as in our study. A previous study that included adjustment of the analysis results for the noise level recorded during the examination did not find a conclusive effect.[15]

Efforts were particularly made to carefully assess the children's exposure to ambient noise: the noise model was produced specifically for this study, and noise measurement was conducted at the residences of 44 children to identify the noise sources and to validate and calibrate the noise exposure model data.[27] To provide individual noise exposure information, we used an exposure assessment approach quite similar to that of Eriksson et al.,[34] who manually identified the place of residence from the home address coordinates using a Geographical Information System (GIS) and survey data on the dwelling's orientation. In this study, we also took into account the floor of the house and precisely localized the children's bedroom façades. Furthermore, because until 2006, the placement of pupils into public schools was decided by the municipalities and depended on the home address of the pupil, we can consider that children who did not relocate residences did not change schools. As a consequence, the noise levels we calculated at the school were used as chronic exposure indicators of the noise at school. In addition, to take into account the fact that children moved to different classrooms each year, we chose to calculate the average of the ambient environmental noise exposure in front of each school facade.

Numerous potential confounding factors were included in the analysis. Multilevel analyses were conducted to examine both the school-level and individual-level

findings and, in particular, to adjust for the household socioeconomic characteristics and the parents' educational levels, which were completed directly by the children's families. However, similar to the previous studies on the effects of environmental noise on children's cognition, the limitations of this study include the lack of a classroom or home acoustics assessment. Another limitation of this study was the lack of an adjustment for the children's health, such as low birth weight, preterm birth,[22] or a long-standing illness.[8,9,14,15]

Several studies have shown that tasks involving central processing and language comprehension, such as reading, attention, problem-solving, and memory, are affected by noise.[5,6,35] The global scores in French and mathematics that we used in this study are partially based on several of these skills, such as reading comprehension in the French test and problem-solving in the mathematics test. Our results are consistent with the findings of these studies. Numerous studies have focused on reading comprehension.[9,10,12,14,36] On the other hand, only a few studies have investigated the relationship between performance in mathematics and outdoor noise exposure[11,25] and the results of these studies were inconstant after adjustment for socio-economic status.

In assessing the cognition effect, the World Health Organization[2] recommends taking into account the fact that children spend the daytime at school and the nighttime at home. The effect of daytime noise exposure at school is now well established, although more so for aircraft noise[9,10,12,14,36] than for road traffic noise,[15,24,25] and this effect was confirmed in our study. Aircraft noise exposure at home was found to be associated with a cognition effect,[9,13,36] as was ambient community road traffic noise.[24] However, the combined effects of noise exposure at home and at school have only been assessed in the vicinity of an airport, except in the study by Belojevic et al.,[23] who studied road traffic noise exposure in the city center of Belgrade. Neither Stansfeld et al.[36] nor Clark et al.[9] attributed an additional effect to noise exposure at home when daytime noise exposure at school was considered. However, the high correlation between aircraft noise levels at home and at school may explain their results. In contrast, Belojevic et al.[23] identified an effect of the noise exposure at home but not at school. Our results appear to indicate that a correlation exists between the children's French performance and ambient noise at home, although it was only borderline significant after adjusting for ambient noise at school. Based on our study and the previous literature, the effect of noise exposure at home on school performance cannot be excluded. In addition, contrary to the findings for daytime noise exposure, nighttime noise exposure could affect cognition through an indirect pathway by reducing sleep quality or impairing children's ability to perform tasks that are dependent on storage.[1] The association between nighttime noise exposure and cognition should focus on tasks running while the child is asleep.[1]

In the French educational system, pupils with learning disabilities can repeat one school year to fill in gaps and consolidate the acquired skills. Repeating was assessed by comparing the ages of the children who participated in the study with the expected age of children in key stage 2, year 4. Children who have already repeated a year were found living in a location or attending a school that was exposed to higher noise levels. However, when the children's ages were included in the multilevel models, the correlation between noise exposure and school performance was less significant. Under these conditions, the adjustment for age likely contributes to over-adjustment.

The use of different noise indexes to quantify children's noise exposure in previous studies, as well as the consideration of combined vs. unique noise sources and different time periods, makes between-study comparisons difficult. In this study, the exposure of the children to noise was quantified by a unique noise index that

combined the noise levels from all sources, in a manner similar to that used by Lercher et al.[24] and Shield et al..[25] The noise exposure at home was, on average, slightly higher than that assessed by Lercher et al.[24] in small towns, but lower than that reported in studies of major road traffic.[16–18,23] In studies around airports, noise sources are considered separately,[8,9,14,15,36] and the road traffic noise level is generally lower than in ambient noise studies.[24,25] As a consequence, no additional effect of road traffic noise is highlighted. As with the noise–annoyance response, the nature of the noise sources may also be relevant: at the same level of noise exposure, the percentage of highly annoyed people is higher with aircraft noise.[37,38]

Road traffic is a shared source of noise and air pollution, and there is the potential for correlated exposures that may lead to confounding in epidemiologic studies.[39] Furthermore, poor air quality in the classroom could result from a lack of ventilation due to closing of windows to reduce external noises.[40] We did not assess these parameters in our study. However, Cohen et al.[41] reported higher nitrogen dioxide (NO_2) levels inside controlled schools compared with those exposed to aircraft noise. According to two recent studies on traffic-related air pollution and transportation noise, the moderate NO_2 exposure encountered at the schools did not appear to confound the association between noise exposure and cognition.[42,43]

In conclusion, ambient noise exposures at school and at home were individually associated with impaired performance before and after adjusting for confounding factors. Long-term impacts of noise could be assessed by following the pupils that participated to this study for 3 years until their middle school national standardized assessment tests. The magnitude of the observed effect on school performance may appear modest, but should be considered in light of the number of people who are potentially chronically exposed to similar environmental noise levels. Particular attention should be given to both the school and the home environment to protect children against the adverse effects of noise.

ACKNOWLEDGMENTS

This work was made possible by the unconditional support of Christine Dodane (Inspection académique du Doubs). We are grateful to the children, families, and teachers who cooperated in this study. We would also like to thank Laurence Tilatti, Valérie Ninucci, Marie-Caroline Clément, and Jean-Marc Cote for their dedication to this project. This research was supported by the French Ministry of Environment and Sustainable Development (MEDD) as part of PREDIT, the French research program on land transportation (grant number CV05000161, established on January 27, 2006). The funder had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

REFERENCES

1. World Health Organization. Night noise guidelines for Europe. Copenhagen: World Health Organization; 2009:162. Available at: http://www.euro.who.int/en/what-we-do/health-topics/environment-and-health/noise/publications/2009/night-noise-guidelines-for-europe. Accessed December 12, 2011.
2. World Health Organization. Burden of disease from environmental noise. Quantification of healthy life years lost in Europe. Copenhagen: World Health Organization; 2011:108. Available at: http://www.euro.who.int/en/what-we-do/health-topics/environment-and-health/noise/publications/2011/burden-of-disease-from-environmental-noise.-quantification-of-healthy-life-years-lost-in-europe. Accessed December 12, 2011.

3. Clark C, Stansfeld SA. The effect of transportation noise on health and cognitive development: a review of recent evidence. *Int J Comp Psychol*. 2007; 20(2): 145–158.
4. Sharp D. Noisy Days, Noisy Nights. *J Urban Health*. 2010; 87(3): 349–351. doi:10.1007/s11524-010-9440-x.
5. Shield B, Dockrell J. The effects of noise on children at school: a review. *Build Acoust*. 2003; 10(2): 97–116. doi:10.1260/135101003768965960.
6. Hygge S. Noise and Cognition in Children. In: *Encyclopedia of Environmental Health*. Burlington, VT: Elsevier; 2011:146–151. Available at: http://www.sciencedirect.com/science/article/pii/B9780444522726002610. Accessed August 3, 2012.
7. Cohen S. *Behavior, health, and environmental stress*. New York, NY: Plenum Press; 1986.
8. Van Kempen E, van Kamp I, Nilsson M, et al. The role of annoyance in the relation between transportation noise and children's health and cognition. *J Acoust Soc Am*. 2010; 128(5): 2817–2828. doi:10.1121/1.3483737.
9. Clark C, Martin R, van Kempen E, et al. Exposure-effect relations between aircraft and road traffic noise exposure at school and reading comprehension: the RANCH project. *Am J Epidemiol*. 2006; 163(1): 27–37. doi:10.1093/aje/kwj001.
10. Haines MM, Stansfeld SA, Head J, Job RFS. Multilevel modelling of aircraft noise on performance tests in schools around Heathrow Airport London. *J Epidemiol Community Health*. 2002; 56(2): 139–144.
11. Haines MM, Stansfeld SA, Brentnall S, et al. The West London Schools Study: the effects of chronic aircraft noise exposure on child health. *Psychol Med*. 2001; 31(8): 1385–1396.
12. Hygge S, Evans GW, Bullinger M. A Prospective Study of Some Effects of Aircraft Noise on Cognitive Performance in Schoolchildren. *Psychol Sci*. 2002; 13(5): 469–474. doi:10.1111/1467-9280.00483.
13. Matsui T, Stansfeld S, Haines M, Head J. Children's cognition and aircraft noise exposure at home–the West London Schools Study. *Noise Health*. 2004; 7(25): 49–58.
14. Stansfeld S, Berglund B, Clark C, et al. Aircraft and road traffic noise and children's cognition and health: a cross-national study. *Lancet*. 2005; 365(9475): 1942–1949.
15. Van Kempen E, van Kamp I, Lebret E, Lammers J, Emmen H, Stansfeld S. Neurobehavioral effects of transportation noise in primary schoolchildren: a cross-sectional study. *Environ Health*. 2010; 9: 25. doi:10.1186/1476-069X-9-25.
16. Cohen S, Glass DC, Singer JE. Apartment noise, auditory discrimination, and reading ability in children. *J Exp Soc Psychol*. 1973; 9(5): 407–422. doi:10.1016/S0022-1031(73)80005-8.
17. Lukas JS, DuPree RB. Effects of freeway noise on academic achievement of elementary school children. *J Acoust Soc Am*. 1980; 68(S1): S90–S90. doi:10.1121/1.2004993.
18. Sanz SA, García AM, García A. Road traffic noise around schools: a risk for pupil's performance? *Int Arch Occup Environ Health*. 1993; 65(3): 205–207. doi:10.1007/BF00381157.
19. Lercher P. Combined Noise Exposure at Home. In: Jerome O. Nriagu, ed. *Encyclopedia of Environmental Health*. Burlington, VT: Elsevier; 2011:764–777. Available at: http://www.sciencedirect.com/science/article/pii/B9780444522726002543. Accessed November 17, 2012.
20. European Environment Agency. Transport at a crossroads: TERM 2008: indicators tracking transport and environment in the European Union. Luxembourg: Office for Official Publications of the European Communities; 2009.
21. Evans GW, Lercher P, Meis M, Ising H, Kofler WW. Community noise exposure and stress in children. *J Acoust Soc Am*. 2001; 109(3): 1023–1027.
22. Lercher P, Evans GW, Meis M, Kofler WW. Ambient neighbourhood noise and children's mental health. *Occup Environ Med*. 2002; 59(6): 380–386. doi:10.1136/oem.59.6.380.
23. Belojevic G, Evans GW, Paunovic K, Jakovljevic B. Traffic noise and executive functioning in urban primary school children: the moderating role of gender. *J Environ Psychol*. 2012; 32(4): 337–341. doi:10.1016/j.jenvp.2012.05.005.
24. Lercher P, Evans GW, Meis M. Ambient Noise and Cognitive Processes among Primary Schoolchildren. *Environ Behav*. 2003; 35(6): 725–735. doi:10.1177/0013916503256260.

25. Shield BM, Dockrell JE. The effects of environmental and classroom noise on the academic attainments of primary school children. *J Acoust Soc Am*. 2008; 123(1): 133–144. doi:10.1121/1.2812596.
26. Pujol S, Berthillier M, Defrance J, et al. Urban ambient outdoor and indoor noise exposure at home: a population-based study on schoolchildren. *Appl Acoust*. 2012; 73(8): 741–750. doi:10.1016/j.apacoust.2012.02.007.
27. Pujol S, Houot H, Berthillier M, et al. Modélisation de l'exposition au bruit en milieu urbain et études épidémiologiques: quelles sources sonores ? In: Actes des Neuvièmes rencontres de Théo Quant. Besançon: Foltête J.-C.; 2009:10. Available at: http://thema.univ-fcomte.fr/theoq/pdf/2009/TQ2009%20ARTICLE%2067.pdf. Accessed October 24, 2013.
28. European Commission. Directive 2002/49/EC of the European Parliement and of the Concil of 25 June 2002 related to the assesment and management of environmental noise.; 2002.
29. CSTB. MITHRA 5.0, manuel technique.; 2002.
30. Institut national de la statistique et des études économiques (INSEE). Les nomenclatures des professions et catégories socio-professionnelles (CSP) 2003 - Niveau 1 - Liste des catégories socioprofessionnelles agrégées. 2003. Available at: http://www.insee.fr/fr/methodes/default.asp?page=nomenclatures/pcs2003/liste_n1.htm. Accessed November 16, 2012.
31. Goldstein H. *Multilevel Statistical Models*. 2nd ed. London: Edward Arnold; 1995.
32. Rasbash J, Charlton C, Jones K, Pillinger R. Bristol University | Centre for Multilevel Modelling | Manual supplement for MLwiN 2.14. 2009. Available at: http://www.bristol.ac.uk/cmm/software/mlwin/download/manuals.html. Accessed January 26, 2012.
33. Cornelie P. Les réponses des élèves de CE2 à l'évaluation de septembre 2006. 2006. Available at: http://test.evace26.education.gouv.fr/sitearchive/archive2006/cfscore.htm. Accessed November 26, 2012.
34. Eriksson C, Nilsson ME, Stenkvist D, Bellander T, Pershagen G. Residential traffic noise exposure assessment: application and evaluation of European Environmental Noise Directive maps. *J Expo Sci Environ Epidemiol*. 2012:1–8. doi:10.1038/jes.2012.60.
35. Evans GW, Lepore SJ. Non-auditory effects of noise on children: a critical review. Life Course Institute, College of Human Ecology, Cornell University; 1993.
36. Stansfeld S, Hygge S, Clark C, Alfred T. Night time aircraft noise exposure and children's cognitive performance. *Noise Health*. 2010; 12(49): 255. doi:10.4103/1463-1741.70504.
37. Van Kempen EEMM, van Kamp I, Stellato RK, et al. Children's annoyance reactions to aircraft and road traffic noise. *J Acoust Soc Am*. 2009; 125(2): 895–904. doi:10.1121/1.3058635.
38. Miedema HM, Oudshoorn CG. Annoyance from transportation noise: relationships with exposure metrics DNL and DENL and their confidence intervals. *Environ Health Perspect*. 2001; 109(4): 409–416.
39. Montazami A, Wilson M, Nicol F. Aircraft noise, overheating and poor air quality in classrooms in London primary schools. *Build Environ*. 2012; 52(0): 129–141. doi:10.1016/j.buildenv.2011.11.019.
40. Montazami A, Wilson M, Nicol F. Aircraft noise, overheating and poor air quality in classrooms in London primary schools. *Build Environ*. 2012; 52: 129–141. doi:10.1016/j.buildenv.2011.11.019.
41. Cohen S, Evans GW, Krantz DS, Stokols D. Physiological, motivational, and cognitive effects of aircraft noise on children: moving from the laboratory to the field. *Am Psychol*. 1980; 35(3): 231–243. doi:10.1037/0003-066X.35.3.231.
42. Clark C, Crombie R, Head J, van Kamp I, van Kempen E, Stansfeld SA. Does Traffic-related Air Pollution Explain Associations of Aircraft and Road Traffic Noise Exposure on Children's Health and Cognition? A Secondary Analysis of the United Kingdom Sample From the RANCH Project. *Am J Epidemiol*. 2012; 176(4): 327–337. doi:10.1093/aje/kws012.
43. Van Kempen E, Fischer P, Janssen N, et al. Neurobehavioral effects of exposure to traffic-related air pollution and transportation noise in primary schoolchildren. *Environ Res*. 2012; 115: 18–25. doi:10.1016/j.envres.2012.03.002.