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

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**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*

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

## 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.<sup>1-4</sup> In the past 30 years, many investigations have examined the effects of noise on the learning and performance of children at school.<sup>5</sup> There is growing scientific evidence that elevated noise levels and prolonged noise exposures impair cognition, particularly attention, reading, memory, learning, and problem-solving.<sup>6</sup> Several pathways have been proposed to explain the cognitive effects of noise exposure: reduction of speech intelligibility,<sup>5</sup> impaired attention (gate out distraction),<sup>6</sup> indiscriminate filtering out of noise,<sup>7</sup> annoyance,<sup>8</sup> and indirect effects mediated by sleep disturbance.<sup>1</sup> Most of the published work on the effects of external noise has concerned pupils in schools exposed to noise due to aircraft<sup>9-15</sup> or freeway traffic.<sup>16-18</sup>

People living in urban areas are typically surrounded by a mixture of sounds associated with humans and their activities.<sup>19</sup> According to the European Environmental Agency, road traffic is by far the main source of exposure to transportation noise in Europe.<sup>20</sup> The non-auditory consequences of typical ambient noise exposure on children have already been highlighted, including stress,<sup>21</sup> mental health effects,<sup>22</sup> and neurobehavioral effects.<sup>23</sup> 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.<sup>24</sup> 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<sup>25</sup> 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.<sup>26</sup> 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.,<sup>27</sup> in accordance with the European Commission's Environmental Noise Directive 2002/49/CE,<sup>28</sup> using the noise prediction software MITHRA.<sup>29</sup> 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.<sup>28</sup> 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,<sup>30</sup> 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<sup>31</sup> 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 ( $p$ )  $\leq 0.20$  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).<sup>32</sup>

### Ethics

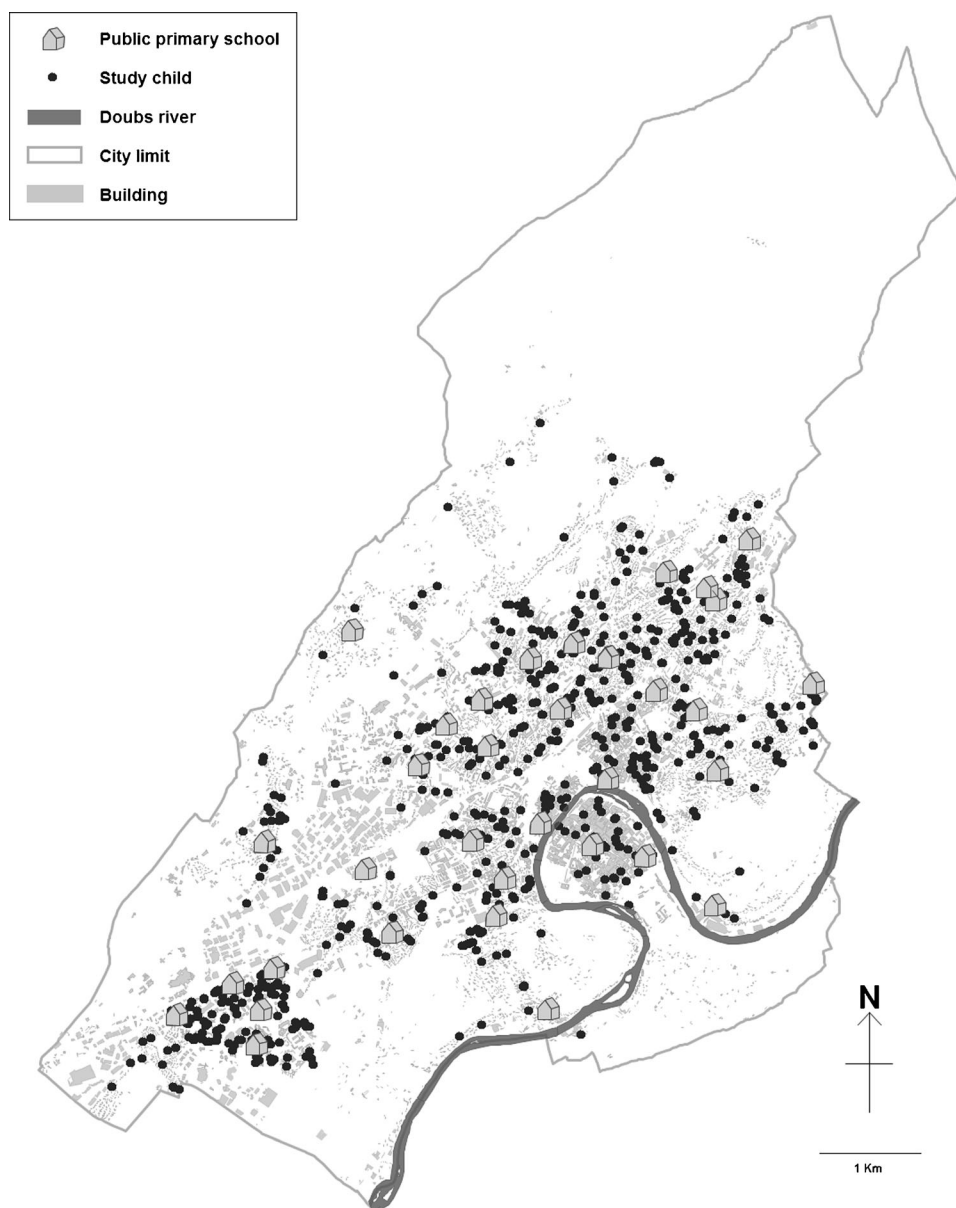
This study was approved by the French National Advisory Committee for the Treatment of Information in Health Research (CCTIRS) and the French National Computing and Freedom Committee (CNIL).

## 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)

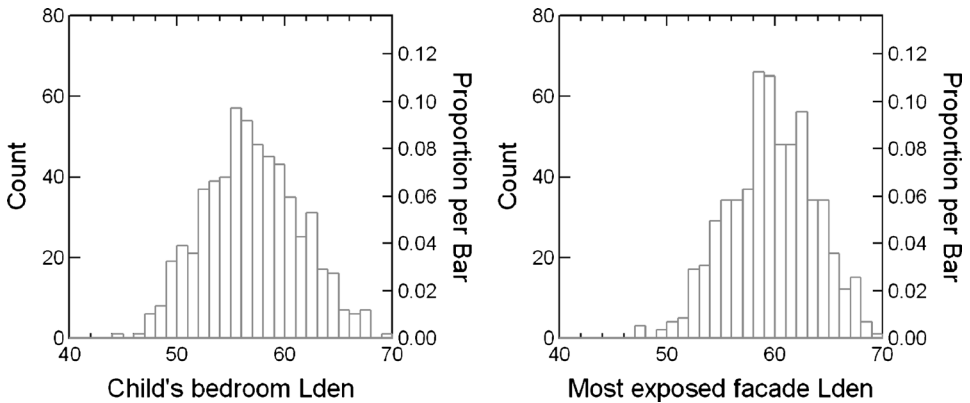
|   | <i>n</i> | %    |
|---|----------|------|
| Household characteristics   |          |      |
| Household socio-economic status <sup>a</sup> (missing values: 43) |          |      |
| SES-1   | 57       | 10.5 |
| SES-2   | 161      | 29.6 |
| SES-3   | 148      | 27.2 |
| SES-4   | 178      | 32.7 |
| 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 |

<sup>a</sup>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





|                                      |        |       |        |       |        |       |     |        |                |
|--------------------------------------|--------|-------|--------|-------|--------|-------|-----|--------|----------------|
| Missing value                        |        |       |        |       |        |       |     |        |                |
| Parents' employment status           |        |       |        |       |        |       |     |        |                |
| No full-time worker                  |        |       |        |       |        |       |     | 0.27   | -5.00 to 5.54  |
| At least one full-time worker        |        |       |        |       |        |       | Ref | 1.94   | -0.56 to 4.44  |
| Missing value                        |        |       |        |       |        |       |     | -7.16  | -16.99 to 2.67 |
| Random parameters                    |        |       |        |       |        |       |     |        |                |
| Level 2: school                      | 53.07  | 16.17 | 48.84  | 15.11 | 46.42  | 14.46 |     | 18.69  | 6.82           |
| Level 1: pupil                       | 169.90 | 10.26 | 173.15 | 10.46 | 169.85 | 10.26 |     | 135.98 | 8.21           |
| Percentage of the explained variance | 3.1    |       | 3.6    |       | 6.0    |       |     | 32.8   |                |

\*Due to missing values (reading is a leisure activity:  $n = 7$ ; main language spoken at home:  $n = 3$ ).  $\beta$  = 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 |                 |                   |
|--|---------|----------------|-------------------|---------|----------------|-------------------|---------|-----------------|-------------------|
|  | $\beta$ | 95 % CI        | <i>p</i>          | $\beta$ | 95 % CI        | <i>p</i>          | $\beta$ | 95 % CI         | <i>p</i>          |
| <b>Independent variables</b>                       |         |                |                   |         |                |                   |         |                 |                   |
| Intercept  | 69.83   |                |                   | 53.87   |                |                   | 56.89   |                 |                   |
| L <sub>den</sub> 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 <sub>Aeq,day</sub> 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              |
| <b>Sex</b>   |         |                |                   |         |                |                   |         |                 |                   |
| Female   | Ref     |                |                   | Ref     |                |                   | Ref     |                 |                   |
| Male   | 4.43    | 1.83 to 7.03   | <10 <sup>-3</sup> | 4.43    | 1.83 to 7.03   | <10 <sup>-3</sup> | 5.19    | 2.67 to 7.72    | <10 <sup>-3</sup> |
| <b>Age</b>   |         |                |                   |         |                |                   |         |                 |                   |
| ≤8 years old                                       | Ref     |                |                   | Ref     |                |                   | Ref     |                 |                   |
| >8 years old                                       |         |                |                   |         |                |                   | -10.83  | -14.74 to -6.92 | <10 <sup>-3</sup> |
| Missing value                                      |         |                |                   |         |                |                   | 6.85    | 1.84 to 11.86   |                   |
| <b>Mother's education</b>                          |         |                |                   |         |                |                   |         |                 |                   |
| Elementary school                                  | Ref     |                |                   | Ref     |                |                   | Ref     |                 |                   |
| Middle school                                      | 5.29    | -3.91 to 14.49 | <10 <sup>-3</sup> | 5.29    | -3.91 to 14.49 | <10 <sup>-3</sup> | 3.50    | -5.43 to 12.44  | <10 <sup>-3</sup> |
| High school  | 9.60    | 0.60 to 18.60  |                   | 9.60    | 0.60 to 18.60  |                   | 6.26    | -2.55 to 15.06  |                   |
| University   | 15.66   | 6.61 to 24.71  |                   | 15.66   | 6.61 to 24.71  |                   | 11.71   | 2.84 to 20.58   |                   |
| Missing value                                      | 3.21    | -6.37 to 12.79 |                   | 3.21    | -6.37 to 12.79 |                   | 2.00    | -7.31 to 11.30  |                   |
| <b>Household socio-economic status</b>             |         |                |                   |         |                |                   |         |                 |                   |
| SES-1  | Ref     |                |                   | Ref     |                |                   | Ref     |                 |                   |
| SES-2  | 1.19    | -3.64 to 6.01  | 0.15              | 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  |                   | 1.16    | -3.98 to 6.29  |                   | 2.07    | -2.92 to 7.05   |                   |
| SES-4  | 2.49    | -2.52 to 7.51  |                   | 2.49    | -2.52 to 7.51  |                   | 3.50    | -1.37 to 8.38   |                   |
| Missing value                                      | -5.55   | -12.34 to 1.24 |                   | -5.55   | -12.34 to 1.24 |                   | -3.61   | -10.25 to 3.03  |                   |
| <b>Parents' employment status</b>                  |         |                |                   |         |                |                   |         |                 |                   |
| No full-time worker                                | Ref     |                |                   | Ref     |                |                   | Ref     |                 |                   |
| At least one full-time worker                      | 2.82    | -0.45 to 6.10  | 0.14              | 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 |                   | 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   |       |

$\beta$  = 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,<sup>12,24</sup> 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).<sup>33</sup> 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.<sup>6,12,24</sup> Some authors have measured the indoor or outdoor noise level during tests to adjust for the noise level during the analysis.<sup>8,9,14,15</sup> Several studies have group-administered cognitive performance tests in the classroom,<sup>8-10,13-15,18</sup> 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.<sup>15</sup>

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.<sup>27</sup> To provide individual noise exposure information, we used an exposure assessment approach quite similar to that of Eriksson et al.,<sup>34</sup> 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,<sup>22</sup> or a long-standing illness.<sup>8,9,14,15</sup>

Several studies have shown that tasks involving central processing and language comprehension, such as reading, attention, problem-solving, and memory, are affected by noise.<sup>5,6,35</sup> 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.<sup>9,10,12,14,36</sup> On the other hand, only a few studies have investigated the relationship between performance in mathematics and outdoor noise exposure<sup>11,25</sup> and the results of these studies were inconstant after adjustment for socio-economic status.

In assessing the cognition effect, the World Health Organization<sup>2</sup> 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<sup>9,10,12,14,36</sup> than for road traffic noise,<sup>15,24,25</sup> and this effect was confirmed in our study. Aircraft noise exposure at home was found to be associated with a cognition effect,<sup>9,13,36</sup> as was ambient community road traffic noise.<sup>24</sup> 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.,<sup>23</sup> who studied road traffic noise exposure in the city center of Belgrade. Neither Stansfeld et al.<sup>36</sup> nor Clark et al.<sup>9</sup> 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.<sup>23</sup> 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.<sup>1</sup> The association between nighttime noise exposure and cognition should focus on tasks running while the child is asleep.<sup>1</sup>

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.<sup>24</sup> and Shield et al.<sup>25</sup> The noise exposure at home was, on average, slightly higher than that assessed by Lercher et al.<sup>24</sup> in small towns, but lower than that reported in studies of major road traffic.<sup>16–18,23</sup> In studies around airports, noise sources are considered separately,<sup>8,9,14,15,36</sup> and the road traffic noise level is generally lower than in ambient noise studies.<sup>24,25</sup> 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.<sup>37,38</sup>

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.<sup>39</sup> Furthermore, poor air quality in the classroom could result from a lack of ventilation due to closing of windows to reduce external noises.<sup>40</sup> We did not assess these parameters in our study. However, Cohen et al.<sup>41</sup> reported higher nitrogen dioxide (NO<sub>2</sub>) 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<sub>2</sub> exposure encountered at the schools did not appear to confound the association between noise exposure and cognition.<sup>42,43</sup>

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.

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