# Indoor noise exposure at home: a field study on urban schoolchildren

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# Indoor noise exposure at home: a field study on urban schoolchildren

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Abstract

To evaluate indoor noise levels and to investigate the potential factors that may be related to, an eight-day noise measurement campaign was conducted in the homes of 44 schoolchildren attending the public primary schools of Besançon (France). The presence of the inhabitants in the dwelling and the noisy events occurring indoors and outdoors were daily collected using a time-location-activity diary (TLAD); 902 time periods were analysed. The indoor noise level increased significantly with the outdoor noise level, along with the duration of presence or level of activity of the inhabitants at home. However, this effect may vary according to the period of day and the day of the week. Moreover, a significant part of the day and evening indoor noise level variability was explained by factors collected by the TLAD: 46% and 45% in the bedroom, 54% and 39% in the main room, respectively. Our results highlight the complexity of the indoor environment in the dwellings of children living in an urban area. Combining the inhabitant presence and indoor noise source descriptors with outdoor noise levels and other dwelling or inhabitant characteristics could improve large-scale epidemiological studies. However, additional efforts are still needed, particularly during the night period.

Key words: noise exposure; indoor noise sources; children; dwelling; multilevel model; field study

Practical implications

The relationship between the ambient outdoor and indoor noise levels at home is complex. The indoor sources contribution can be the predominant fraction of the day and evening noise levels in the dwellings of children living in an urban area. Considering the time spent at home by a child, both outdoor and indoor noise sources should be considered to improve the exposure assessment. The use of a TLAD seems to be a solution for large-scale epidemiologic studies to evaluate the detrimental effects of noise on the human health.

1. Introduction

The relationship between noise pollution and human health has been the subject of numerous studies over the last two decades. Researchers have recently focused increased attention on the relationship between noise and non-auditory effects, such as annoyance, hypertension, cardiovascular diseases, sleep disturbance, and cognitive impairments (Clark and Stansfeld, 2007; Passchier-Vermeer and Passchier, 2000; Paunovic et al., 2011).

People are exposed to environmental noise of various origins: transport (road, rail, or air traffic), construction and industry, community sources (neighbourhood, bars and restaurants, discotheques), and social or leisure sources (World Health Organization, 2011). The assessment of exposure to noise requires the consideration of many factors, including measured or modelled exposures, choice of noise indicators, population distribution, time-activity patterns of the exposed population and combined exposures to multiple sources of noise (World Health Organization, 2011).

Advances have been made in assessing the actual exposure of populations to noise sources, such as air traffic and road traffic (World Health Organization, 2011). Thus, noise exposure mapping is a commonly adopted step in the process of estimating the noise exposure of a population (European Commission, 2002; Murphy and King, 2010; Seong et al., 2011; Xie et al., 2011). However, only outdoor exposure is estimated, typically in front of either the most exposed facade or the bedroom facade of the dwelling in which the participant subjects reside.

According to the United States Environmental Protection Agency (US EPA), children spend approximately 90% of their time indoors and over 60% of their time within their own residence (US EPA, 2009). Generally speaking, noise pollution within the indoor environment is a complex mixture of agents migrating from outdoors, in addition to agents generated by indoor sources (Le Cann et al., 2011). Pirrera et al. (2010) recommend to record the indoor noise level in the bedroom of each participant to provide the most exact and reliable noise pollution estimates. Thus, several epidemiological studies have used indoor noise measurements to assess the relationship between noise and health. However, these studies are typically conducted using limited human samples (Aasvang et al., 2011; Graham et al., 2009; Pirrera et al., 2011) or are based on short-term noise level measurements (Babisch et al., 2009; Evans and Marcynyszyn, 2004). Alternative methods for determining the indoor noise levels consider the indoor noise level to be the difference between the outdoor noise level and the facade insulation (Amundsen et al., 2011; Ohrström, 2004; Pirrera et al., 2010; World Health Organization, 2009). This attractive method can be applied to a large number of people and allows researchers to calculate the proportion of subjects exposed to harmful noise levels. However, this method introduces uncertainty of the inhabitants' noise exposure assessment on an individual level and is still under investigation.

A previous noise measurement campaign conducted within the places of residence of schoolchildren examined the variability of weekly indoor and outdoor noise levels (Pujol et al., 2012). The aims of the present study are to quantify the daily indoor noise exposure of children living in an urban area and to analyse the factors that may influence noise level variability. Specifically, day-to-day variability factors within the same dwelling ("within-dwelling variability") and variability factors that differ between separate dwellings ("between-dwelling variability") are examined.

## 2. Methods

The population characteristics and the methods used in this study have been previously reported by Pujol et al. (2012). The major points are described below.

### 2.1 Population

This study population consisted of 8- and 9-year-old school-children who were randomly selected from among the 900 pupils attending one of the 35 public primary schools in key stage 2, year 4 in the French city of Besançon in 2006-2007. The parents of the children were contacted by telephone for consent to participate in the study and to determine each child's inclusion eligibility, which included the following characteristics: residence within the city at the same residence for at least one year, the child's bedroom being located either higher than the ground floor or at ground level with a private garden or courtyard, and a bedroom window of an appropriate size to affix the outdoor microphone. Forty-four dwellings were selected and equipped with microphones in the order in which the families agreed to participate, taking into account the availability of the inhabitants and the measurement equipment and avoiding long holiday periods and unusual living conditions.



2.2 Dwellings and family characteristics

Before the beginning of the measurement session, the presence of indoor noise sources in the dwelling (radio, television, musical instrument, computer, or others) and the number of children sleeping in the bedroom were recorded by the operator. Standardised questionnaires were distributed to the families to collect the household socio-economic characteristics (single parenthood and parental occupation, employment status, and educational level); family size; the number of residents; residency duration; the child's age, sex, and birth order; and dwelling characteristics (number of rooms, floor level, type of dwelling, and type of windows). The families were also asked to record the following information for the duration of the measurement session in a time-location-activity diary (TLAD) by periods of 30 minutes: the presence of adults and children in the dwelling, noisy events occurring indoors (use of television, radio, musical instruments, or household appliances), noisy events occurring outdoors, and opening of the windows.

## 2.3 Noise measurement

The study was conducted from December 2006 to July 2007 using three class 1 acoustic equipment chains, each composed of a sound level meter (Blue Solo®, 01dB-Metravib) and a front-end acquisition equipment (Harmonie® or Symphonie®, 01dB-Metravib). Three microphones were used in each dwelling: one microphone was used in the room where the child spent most of the time, i.e. the main room; one microphone was used in the child's bedroom; and one microphone was used outdoors (2 m in front of the child's bedroom window). The microphone location was chosen carefully, considering acoustic and family constraints and avoiding locations close to walls, windows, and doors. The microphone was placed 1.15 m above the floor, corresponding to the approximate height of a child's ear.

Equivalent continuous A-weighted sound levels ($L_{Aeq}$, in dB) were measured every second during an eight-day period, according to the French standard (NF S 31-010, 1996). The measurement chains were calibrated at the beginning and at the end of the measurement sessions.

In parallel, theoretical outdoor noise levels in front of the main room facade were calculated using a strategic noise map (Pujol et al., 2009) that was built in accordance with the European environmental noise directive 2002/49/CE (European Commission, 2002).The noise prediction software MITHRA (CSTB, 2002) was used to position virtual receivers were on the floor of the dwelling, at 2m in front of the facade of the main room.

## 2.4 Data processing

For each measurement location, $L_{Aeq,\ day}$ (6:00-18:00), $L_{Aeq,\ evening}$ (18:00-22:00) and $L_{Aeq,\ night}$ (22:00-6:00) were calculated. Data recorded during the first day of measurement and during the following unfavourable measurement conditions were excluded from the analyses:

rainfall or strong wind (wind speed higher than 5 $m.s^{-1}$), unusual outdoor or indoor sound events reported by families (fairs, demonstrations, and open-air concerts) and periods for which acoustic data were available for less than half the time.

Three classes of socio-economic status were defined using the parents' occupations, according to the French National Institute of Statistics and Economic Studies classification. The class of the more privileged member of the couple was used to determine the household socio-economic status. Crowding was defined based on the number of people per room. Both apartment buildings and semi-detached houses were defined as collective dwellings.

The data collected in the TLAD were used to quantify the inhabitants' presence in the dwelling, the occurrence of noisy events (in the child's bedroom, out of the child's bedroom, outdoors), and the opening of the windows in the child's bedroom and the main room for each period (day, evening, and night). Periods were excluded from the analysis if the data were not fulfilled during the totality of the period. The occurrence was defined for each period as the number of 30-min periods associated with an event, as reported by the family, divided by the total number of 30-min periods (i.e. 24 in the day, 8 in the evening and 16 in the night). The occurrence values were multiplied by 100 for convenience. The school calendar was used to determine school days, in addition to the evenings and nights before a school day.

## 2.5 Statistical analysis

Descriptive statistics are presented as the means and standard deviations (SD). To take into account the hierarchical structure of the data, multilevel linear regression models (Goldstein, 1995) were used to assess the associations between the indoor noise level and independent factors, including the outdoor noise level, the TLAD variables, and the dwelling or family characteristics. Two levels were defined, including "day of measurement" (level I) and "dwelling" (level II), to partition the overall variability into "within-dwelling variability" (day-to-day variability, level I) and "between-dwelling variability" (from one dwelling to another, level II). The variables that were associated with the indoor noise level at $P \leq 0.2$ in a univariate analysis were then included in a multivariate analysis using a backward step-by-step elimination procedure. These analyses were only performed on the time periods for which both the TLAD variables and the noise level were available. The proportion 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. Multilevel analyses were also used to test for the period effect on TLAD variables and noise levels. A P-value of 0.05 was used as a threshold for statistical significance. The SYSTAT 12.02 (SYSTAT Software, Inc., Chicago, IL) and MLwiN 2.1 (University of Bristol, UK) (Rasbash et al., 2009) software programs were used to perform the analyses.



### 2.6 Ethics

Permission to conduct this study was given by the French National Committee for the Treatment of Information in Health Research (CCTIRS) and the French National Computing and Freedom Committee (CNIL).

## 3. Results

### 3.1 Sample characteristics

Among the 44 dwellings included in the analysis, 80% were in a collective building. The view from the child's bedroom window was either a courtyard or a grassy area in 61% of the dwellings, whereas the view was a street in 66% of the main room windows. Most of the windows were double-glazed windows, both in the bedroom (75%) and in the main room (82%). Forty-one per cent of the participant children shared their bedroom with another child or two other children. A TV set was present in 32% of the children's bedrooms. The main room was a living room in 89% of the dwellings (n = 39), a separate bedroom in 7% of the dwellings (n = 3), and a kitchen in 4% of the dwellings (n = 2). The number of inhabitants ranged between 2 and 6 (mean = 4.2), and each family had on average 2.4 children (range = 1-4 children). A majority (57%) of the families had an intermediate socio-economic status, whereas 34% had a privileged socio-economic status, and 9% had an underprivileged socio-economic status.

## 3.2 Living conditions

A total of 902 time periods were retained from the 1077 TLAD data. On average, the participant children spent approximately 17 hours per day (67%) at home. A majority of the evening and night periods were spent at home (77% and 90%, respectively), whereas only 48% of the day period was spent at home (Table 1). Unsurprisingly, the inhabitants were significantly more present in the dwelling during the evening and the night periods compared with the day period (all $P < 10^{-3}$). Noisy indoor events were significantly more frequent during the evening period ($P < 10^{-3}$). Window-opening behaviour was prone to both considerable day-to-day and between-dwelling variability. The windows were open every day for 2:07 hours in the child's bedroom and 2:45 hours in the main room on average.

## 3.3 Dwelling noise exposure

Measurements of noise level using $L_{Aeq,day}$, $L_{Aeq,evening}$, and $L_{Aeq,night}$ in the main room, in the child's bedroom, and outdoors are shown in Tables 2 and 3. During the evening, the indoor $L_{Aeq}$ in the main room was significantly higher than outdoors (+ 4.1 dB, $P < 10^{-3}$).

## 3.4 "School day" and "Day before school day"

During school days, both children and adults spent significantly less time at home than when there was no school: 37.1% of the day period vs. 58.3 for the participant child ($P < 10^{-3}$), 36.8% vs. 48.8% for the other children ($P < 10^{-3}$) and 60.0% vs. 67.6 for the adults ($P = 0.01$). The occurrence of the noisy events declared by the family was similar in the child's bedroom (4.2% of the day period on school days vs. 4.1% on days without school). In the main room, the noisy events were less frequent on days of school (20.6% vs. 24.5% on days without school, $P = 0.01$). The indoor $L_{Aeq, day}$ was significantly lower during school days compared with days without school (-3.1 dB in the bedroom and -2.1 dB in the main room, both $P = 10^{-3}$) (Table 2).

Before a school day, both the participant children and the adults spend more time at home than before a day without school (i.e. during the evening 84.0% vs. 68.7%, $P < 10^{-3}$ for the participant child and 88.4% vs. 80.3%, $P = 0.01$ for the adults, respectively and during the night 95.8% vs. 84.1%, $P < 10^{-3}$ for the participant child and 98.4% vs. 94.5%, $P = 0.03$, for the adults, respectively). The indoor $L_{Aeq, evening}$ was significantly higher than before a day without school (+ 2.3 dB in the bedroom and + 2.7 dB in the main room, $P = 0.02$ and 0.01, respectively) (Table 3). Conversely, on a night before a school day, the $L_{Aeq, night}$ was significantly lower than before a day without school in the child's bedroom (- 3.9 dB, $P < 10^{-3}$) but not in the main room (- 1 dB, $P = 0.10$).

The outdoor $L_{Aeq}$ was statistically significantly higher during the day periods of school days (+ 1.2 dB, $P < 10^{-3}$) and slightly lower on a night before a school day (- 0.5 dB, $P = 0.02$). No difference was observed during the evening period.

## 3.5 Multilevel analysis results

Among the variables selected during the univariate analyses, four were no more significant at the issue of the backward step-by-step procedure: type of windows, crowding, noisy outdoor event and the presence of a musical instrument in the main room. The multilevel models for the child's bedroom and the main room are presented in Tables 4 and 5.

Child's bedroom

A significant and positive association was found between the bedroom $L_{Aeq}$ and the outdoor $L_{Aeq}$ during the day and the evening ($P < 10^{-3}$ and $P = 0.04$, respectively), whereas a marginally significant association was found during the night ($P = 0.06$) (Table 4). Each time the outdoor $L_{Aeq,\ day}$ increased by 10 dB, the bedroom $L_{Aeq,\ day}$ increased on average by 3.6 dB. However, this increase was lower during the evening (+ 2.3 dB) and the night (+ 1.7 dB). In the models "day", "evening", "night", the presence of people in the dwelling was associated with an increased bedroom $L_{Aeq}$. However, the influence of the presence of different people in the dwelling depended on the time period. Only the participant child's presence was statistically significant during each time period. Compared with the bedrooms without a TV set, the $L_{Aeq}$ in the bedrooms with a TV set was higher during the day [+ 2.6 dB ($P = 0.03$)] and the evening periods [+ 4.2 dB ($P = 0.01$)]. The indoor $L_{Aeq,\ night}$ was significantly lower when the participant child was sleeping alone in his bedroom (- 2.7 dB, $P = 0.05$) or before a day of school (- 4.1 dB, $P <10^{-3}$).

The proportions of the variance explained by the "day", "evening" and "night" models reached 46%, 45%, and 17%, respectively. When excluding the TLAD variables, the proportions decreased to 16%, 14% and 9%, respectively.

Main room

In the main room, the presence of adults was significantly and positively associated with indoor $L_{Aeq}$, regardless of the time of day (Table 5). The other events described in the TLAD (presence of the participant child, presence of other children, or a noisy event in the dwelling) were also significantly associated with an increased indoor $L_{Aeq}$ in the "day" and "evening" models. A significant and positive association between indoor and outdoor $L_{Aeq}$ was found during the day (β = 3.8; 95% CI = [0.7; 6.8]; P = 0.02). Regarding the evening and night periods, this relationship was not significant (β = 0.9; 95% CI = [-2.1; 3.9]; P = 0.55 and β = 1.2; 95% CI = [-4.3; 6.7]; P = 0.67, respectively). The main room $L_{Aeq}$ was, on average, 1.9 dB lower on a night before a school day than on a night that was not before a school day.

The proportion of variance explained by the "day", ''evening'' and ''night'' models reached 54%, 39% and 3%, respectively. When excluding the TLAD variables, the proportion of the variance that was explained by the models fell to 27%, 10% and 1%, respectively.

## 4. Discussion

This study on noise exposure in schoolchildren aimed to explore the between- and within-dwelling variability of noise levels at home. In addition to the expected between-dwelling variability, the within-dwelling variability of noise levels from the three time periods was significant, as was the course of the week for both indoor and outdoor noise levels. Among the identified factors that influence noise variability, dwelling characteristics and home inhabitants' presence or activities appeared to play a predominant role.

These results were obtained from a large data set based on a six-month acquisition campaign that was conducted at the places of residence of randomly sampled schoolchildren. To insure the quality of the data, approved noise measurement equipment, an adapted standardised measurement protocol and questionnaires were used (Pujol et al., 2012). Furthermore, data control and data processing measures were carefully conducted, including the identification and exclusion of invalid or incomplete time periods and careful verification of the TLAD with the family at the end of each session. However, biases due to the underestimation or underreporting of noisy events due to the absence of parents or wakefulness periods cannot be excluded. Similar to Díaz and Pedrero (2006), whose study relies on a moderate sample size but a long measurement period, the sample size was optimised to include an entire week to quantify fluctuations in family life, including days of school vs. days without school and working days vs. days off. The multilevel multivariate analyses were conducted to control for the repeated structure of the data, to better quantify the day-to-day variability and the factors influencing the day-to-day variability, and to control for confounding effects.

The indoor noise levels increased with the presence or activity of the inhabitants at home, although the influence of these parameters may vary according to the period of the day and the day of the week. Individuals, as well as household items in the dwelling, can be considered to be indoor sound sources and can help to explain a large part of the level and the variability of the indoor noise. This observation was especially true during the day and evening periods, when the inhabitants were awake. The notion of indoor noise sources has already been tackled by several authors (Aasvang et al., 2011; Pirrera et al., 2011). Our results demonstrate the crucial necessity of quantifying noisy events and inhabitants' presence for indoor noise level assessment.

A complex relationship between indoor and outdoor noise levels was underlined. Indeed, the indoor noise level was found to be associated with outdoor noise levels or opening of the windows during the day or the evening periods. Fortunately, this finding strengthens the results of numerous studies or noise regulation policies that are based upon outdoor noise to assess human exposure or evaluate health effects (Belojevic et al., 2008; European Commission, 2002; Mehdi et al., 2011; World Health Organization, 2011, 2009). However, the correlation between increasing bedroom $L_{Aeq}$ and increasing outdoor $L_{Aeq}$ was greater during the day than during the evening; and, the correlation was over two times less during the night and only marginally significant. The same trend can be observed in the main room results. Several factors could explain the nonlinearity of this relationship across the different time periods. First, the concurrence of a higher outdoor noise level, a lower indoor noise source emission and a longer opening time during the day should be considered. Thus, the relationships between the outdoor noise levels and the window opening behaviour (European Commission Working Group on Health and Socio-economic Aspects, 2004) or indoor noise levels (Amundsen et al., 2011) should be taken into consideration. Secondly, the low contribution of the outdoor $L_{Aeq}$ to the indoor $L_{Aeq}$ during the evening and night periods is consistent with the moderate outdoor noise levels. As described in Pujol et al. (2012), the main noise source in this city of 120, 000 inhabitants (INSEE, 2011) is ground transport, including road and rail traffic; however, no motorways crossed the inhabited districts. Due to the facade insulation, the amount of outdoor noise that enters the dwelling is relatively low, especially when the windows are closed. Therefore, indoor noise source emissions become the major contributors to the ambient noise level inside the dwelling. This finding is particularly true in the evening period, when both indoor $L_{Aeq}$ and indoor noisy events, as declared by the inhabitants, are the highest.

The World Health Organization (2009) proposed a default reduction of 21 dB(A) to convert a theoretical outside night noise level on the most exposed facade to an inside night noise level, thereby taking into account the possibility that the windows may be open a large part of the year. Applied to our results, this default reduction index provides an average indoor night noise level that is very close to the observed one (32.5 vs. the observed 33.5 dB(A), after using the +6 dB(A) correction proposed by Amundsen et al. (2011) to convert a bedroom facade to a most exposed facade noise level). When the default reduction index was applied to the main room, the predicted results diverged from the observed results, at, respectively, 33.0 vs. the observed 41.5 dB(A). Thus, whereas the default reduction index may be of interest in a child's bedroom noise level assessment, this parameter does not have a clear predictive value in other rooms, including the main room in our study, or an adult's bedroom (Pirrera et al., 2011).

Many factors have been identified as independent sources of variability, including the presence of people in the dwelling, noisy event occurrences, measurement before a day of school, presence of a TV set in the child's bedroom, the location of the dwelling in a detached house, a child sleeping alone in a bedroom, a child being the eldest child or the number of children living in the dwelling. However, the influence of these parameters may vary according to the time period. When the parameters included in the day and evening models were relatively similar, night-time appeared to be a specific period with its own variability factors. A small number of TLAD parameters were included in the night period multivariate analysis; the night period model explained only a fraction of the noise level variability. Certain permanent noise sources, including ventilation, refrigerator, freezer, electronic equipment, and low power setting, may have not been reported in the TLAD because their contributions may have been masked by the other sources present during the diurnal period. Noises created by the participant child, including body movements during sleep (motility) and respiration, may also increase the ambient noise; these factors were only taken into account by the inhabitants' presence information. Furthermore, the presence and activities of the inhabitants in the dwelling differ among days because the child's activities, time of awakening, and presence are regulated by school timetables. Additionally, school may also influence the child's activities during the night period. For example, a child may have an earlier bedtime on a school night. Conversely, when there is no school the following day, the child may be allowed to watch more TV. Pirrera et al. (2011) did not observe any influence of the weekday on indoor nocturnal noise effects. However, the experimental design of this adult-focused study was not able to compare the working day with the days off as the measurements were performed excluding weekends.

In the risk assessment process, the exposure is the result of the pollutant presence and the time over which a person is in contact with that pollutant (Morawska et al., 2013). TLADs have already been used to describe personal exposure to several pollution sources in epidemiological studies (Meng et al., 2004; Saborit et al., 2009; Viel et al., 2011; Wallace et al., 2006). A self-reported survey recently provided annual individual noise exposure duration of urban adult residents (Neitzel et al., 2012). In our study, the TLAD variables allowed us to assess the effect of the presence of the inhabitants at home on noise occurrence and to quantify the indoor noise source activity. Our results on a child's presence in the dwelling were consistent with the statistics of the US EPA regarding time spent at the residence (US EPA, 2009). Our use of TLAD variables in our multivariate models enhanced the understanding of the indoor noise levels and highly improved the fit of the models. Further studies could evaluate solely the amount of time a child spends at home instead of using conventional noise indicators calculated on standardised time periods. Data obtained in this manner could provide a more accurate assessment of a child's noise exposure in everyday life.

The indoor environment within the dwelling of a child living in an urban area appears to be complex and cannot be easily elucidated from any single factor, including the outdoor noise level and the facade insulation values. Many variability factors differ based on the time of day. In contrast to the outdoor noise level, which can be calculated at a city scale, indoor noise level assessment requires the simultaneous consideration of dwelling and inhabitant characteristics, in addition to outdoor noise levels and noise sources within the dwelling. The use of a TLAD allows the recording of the inhabitants' presence and activities without resorting to the acoustical constraints of the equipment, the long-term recording, and the data processing. The TLAD is a refined alternative that could be distributed to numerous people and combined with the other identified variability factors to improve large-scale indoor home noise exposure assessment.

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Table 1: Living conditions during day, evening and night

| | Day (n = 304) | | Evening (n = 297) | | Night (n = 301) | | |
|---|---|---|---|---|---|---|---|
| TLAD variables | Mean (SD) | Range | Mean (SD) | Range | Mean (SD) | Range | P |
| **Presence in the dwelling** | | | | | | | |
| At least one adult | 63.7 (28.6) | 0-100 | 84.5 (26.5) | 0-100 | 96.4 (16.5) | 0-100 | $<10^{-3}$ |
| Child participant | 47.5 (27.1) | 0-100 | 76.6 (33.4) | 0-100 | 90.1 (28.4) | 0-100 | $<10^{-3}$ |
| At least one other child | 42.7 (35.3) | 0-100 | 63.6 (42.9) | 0-100 | 72.7 (44.0) | 0-100 | $<10^{-3}$ |
| **Noisy events*** | | | | | | | |
| In the child's bedroom | 4.2 (9.3) | 0-66.7 | 8.7 (21.2) | 0-100 | 0.7 (4.5) | 0-50 | $<10^{-3}$ |
| In the main room | 22.5 (20.3) | 0-87.5 | 48.2 (37.0) | 0-100 | 12.2 (15.5) | 0-100 | $<10^{-3}$ |
| Outdoors | 2.9 (9.0) | 0-66.7 | 2.8 (10.7) | 0-100 | 1.3 (7.4) | 0-100 | 0.03 |
| **Window's opening** | | | | | | | |
| In the child's bedroom | 12.0 (22.1) | 0-100 | 10.1 (24.2) | 0-100 | 3.4 (16.4) | 0-100 | $<10^{-3}$ |
| In the main room | 14.0 (25.0) | 0-100 | 13.6 (28.7) | 0-100 | 6.6 (23.6) | 0-100 | $<10^{-3}$ |

The results are expressed as the percentage of time during the considered time period. As an example, at least one adult is present in the dwelling during 63.7 percent of the day period.
SD: Standard deviation
P: Difference between day, evening or night P-value (multilevel analysis)
* Use of television, radio, musical instruments, household appliances, or other noisy event or activity

Table 2: $L_{Aeq,day}$ during days of school and days without school [a] (dB)

| Time and place of measurement | Total | | | Days of school | | Days without school [a] | | |
|---|---|---|---|---|---|---|---|---|
| Day (6:00-18:00) | n | Mean (SD) | Range | n | Mean (SD) | n | Mean (SD) | P [b] |
| Child's bedroom | 298 | 48.2 (5.1) | 23.6-66.2 | 153 | 46.7 (5.8) | 145 | 49.8 (6.5) | $10^{-3}$ |
| Main room | 289 | 55.2 (5.4) | 33.0-75.8 | 151 | 54.1 (6.5) | 138 | 56.2 (5.5) | $10^{-3}$ |
| Outdoors (bedroom) | 273 | 55.4 (5.6) | 40.5-68.5 | 140 | 55.9 (5.5) | 133 | 54.7 (5.2) | $< 10^{-3}$ |
| Outdoors (main room) | 44 | 55.8 (3.4) | 49.9-65.2 | - | - | - | - | - |

[a] Wednesday, Saturday, Sunday, legal holiday, and other school vacation
SD: standard deviation
[b] Difference between days of school and days without school: multilevel analysis P-value

Table 3: $L_{Aeq,evening}$ and $L_{Aeq,night}$ during evenings and nights before a day of school [c] (dB)

| | Total | | | Before a day of school | | Before a day without school [c] | | |
|---|---|---|---|---|---|---|---|---|
| Time and place of measurement | n | Mean (SD) | Range | n | Mean (SD) | n | Mean (SD) | P [d] |
| Evening (18:00-22:00) | | | | | | | | |
| Child's bedroom | 289 | 50.4 (6.5) | 24.0-68.5 | 148 | 51.6 (5.6) | 141 | 49.3 (8.3) | 0.02 |
| Main room | 283 | 58.0 (4.8) | 26.9-87.8 | 148 | 59.2 (4.8) | 135 | 56.5 (5.5) | 0.01 |
| Outdoors (bedroom) | 272 | 54.0 (5.9) | 42.0-68.2 | 135 | 53.6 (6.3) | 137 | 53.9 (5.8) | 0.07 |
| Outdoors (main room) | 44 | 53.9 (3.7) | 47.5-64.4 | - | - | - | - | - |
| Night (22:00-6:00) | | | | | | | | |
| Child's bedroom | 291 | 33.5 (4.6) | 20.8-65.5 | 149 | 31.8 (4.2) | 142 | 35.7 (6.5) | $< 10^{-3}$ |
| Main room | 287 | 41.5 (6.0) | 18.5-77.3 | 149 | 41.2 (6.5) | 138 | 42.2 (6.9) | 0.10 |
| Outdoors (bedroom) | 274 | 47.5 (5.6) | 33.1-63.4 | 141 | 47.2 (5.6) | 133 | 47.7 (5.8) | 0.02 |
| Outdoors (main room) | 44 | 48.0 (3.1) | 42.5-55.7 | - | - | - | - | - |

[c] Tuesday, Friday, Saturday, day before a legal holiday or other school vacation
SD: standard deviation
[d] Difference between before a day of school and before a day without school: multilevel analysis P-value

Table 4: Bedroom noise level: day, evening and night multivariate multilevel linear models

| Independent variable | Day model β | Day model 95% CI | Day model P | Evening model β | Evening model 95% CI | Evening model P | Night model β | Night model 95% CI | Night model P |
|---|---|---|---|---|---|---|---|---|---|
| **Intercept** | 46.55 | | | 46.86 | | | 36.94 | | |
| **Level "DAY OF MEASUREMENT"** | | | | | | | | | |
| ***Outdoor noise level* (unit = 10 dB)*** | 3.57 | [1.94; 5.20] | $<10^{-3}$ | 2.28 | [0.13; 4.44] | 0.04 | 1.76 | [-0.02; 3.54] | 0.06 |
| ***TLAD variables (unit = 1 hour)*** | | | | | | | | | |
| Presence of the participant child | 0.65 | [0.39; 0.91] | $<10^{-3}$ | 0.80 | [0.08; 1.52] | 0.03 | 0.88 | [0.53; 1.22] | $<10^{-3}$ |
| Presence of one adult or more | 0.21 | [-0.02; 0.44] | 0.08 | 1.75 | [0.88; 2.62] | $<10^{-3}$ | 0.54 | [0.00; 1.08] | 0.06 |
| Presence of one other child or more | 0.48 | [0.25; 0.71] | $<10^{-3}$ | 1.35 | [0.72; 1.99] | $<10^{-3}$ | - | - | - |
| Noisy events in the child's bedroom | 0.89 | [0.16; 1.63] | 0.02 | 1.82 | [0.13; 3.52] | 0.04 | - | - | - |
| Bedroom window opening | 0.30 | [0.04; 0.56] | 0.02 | - | - | - | - | - | - |
| ***Measurement before a day of school*** | - | - | - | - | - | - | -4.06 | [-5.37; -2.76] | $<10^{-3}$ |
| **Level "DWELLING"** | | | | | | | | | |
| ***Dwelling characteristics*** | | | | | | | | | |
| Dwelling being in a detached house | -3.17 | [-5.68; -0.67] | 0.02 | - | - | - | - | - | - |
| Presence of a TV in the bedroom | 2.62 | [0.37; 4.87] | 0.03 | 4.21 | [1.14; 7.28] | 0.01 | - | - | - |
| ***Inhabitant's characteristics*** | | | | | | | | | |
| Participant child being the eldest child | 3.05 | [0.86; 5.25] | 0.01 | 5.63 | [2.65; 8.61] | $<10^{-3}$ | - | - | - |
| Participant child sharing his bedroom with (an)other child(ren) | - | - | - | - | - | - | -2.66 | [-5.25; -0.06] | 0.05 |
| Units level "day of measurement" | 273 | | | 272 | | | 274 | | |
| Units level "dwelling" | 43 | | | 44 | | | 44 | | |
| Explained variance proportion (%) | 46 | | | 45 | | | 17 | | |

β: the estimated change of the indoor noise level; CI: confidence interval; P: P-value.
* The outdoor noise level was measured in front of the bedroom facade.

Table 5: Main room noise level: day, evening and night multivariate multilevel linear models

| | Day model | | | Evening model | | | Night model | | |
|---|---|---|---|---|---|---|---|---|---|
| Independent variable | β | 95% CI | P | β | 95% CI | P | β | 95% CI | P |
| **Intercept** | 54.62 | | | 57.10 | | | 42.19 | | |
| **Level "DAY OF MEASUREMENT"** | | | | | | | | | |
| ***Outdoor noise level* (unit = 10 dB)*** | 3.79 | [0.76; 6.83] | 0.02 | - | - | - | - | - | - |
| ***TLAD variables (unit = 1 hour)*** | | | | | | | | | |
| Presence of the participant child | 0.38 | [0.18; 0.58] | $<10^{-3}$ | 0.90 | [0.21; 1.59] | 0.02 | - | - | - |
| Presence of one adult or more | 0.36 | [0.13; 0.59] | 0.01 | 1.63 | [0.79; 2.46] | $<10^{-3}$ | 1.20 | [0.56; 1.84] | $<10^{-3}$ |
| Presence of one other child or more | 0.40 | [0.20; 0.59] | $<10^{-3}$ | 1.03 | [0.44; 1.61] | $<10^{-3}$ | - | - | - |
| Noisy events in the dwelling | 0.25 | [0.01; 0.49] | 0.05 | 1.15 | [0.61; 1.69] | $<10^{-3}$ | - | - | - |
| ***Measurement before a day of school*** | - | - | - | - | - | - | -1.91 | [-3.58; -0.23] | 0.03 |
| **Level "DWELLING"** | | | | | | | | | |
| ***Dwelling characteristics*** | | | | | | | | | |
| Dwelling being in a detached house | 2.45 | [-0.11; 5.01] | 0.07 | 2.72 | [0.00; 5.43] | 0.06 | - | - | - |
| ***Inhabitant's characteristics*** | | | | | | | | | |
| Number of children | 1.48 | [0.10; 2.87] | 0.04 | 1.27 | [-0.15; 2.68] | 0.09 | - | - | - |
| Units level "day of measurement" | 289 | | | 283 | | | 287 | | |
| Units level "dwelling" | 42 | | | 43 | | | 43 | | |
| Explained variance proportion (%) | 54 | | | 39 | | | 3 | | |

β: the estimated change in the indoor noise level; CI: confidence interval; P: P-value.

* The outdoor noise level was calculated in front of the main room facade using a strategic noise map.