The Journal of the Acoustical Society of America

SEPTEMBER 20 2023

Indoor soundscape in primary school classrooms[a]

Chiara Visentin ; Simone Torresin ; Matteo Pellegatti; Nicola Prodi

J. Acoust. Soc. Am. 154, 1813–1826 (2023)
https://doi.org/10.1121/10.0020833

JASA ARTICLE

Indoor soundscape in primary school classrooms[a)]

Chiara Visentin,[1,b),c)] Simone Torresin,[2,d)] Matteo Pellegatti,[1,b)] and Nicola Prodi[1]
[1]*Department of Engineering, University of Ferrara, Via Saragat 1, 44122 Ferrara, Italy*
[2]*Institute for Renewable Energy, Eurac Research, Via A. Volta/A. Volta Straße 13/A, 39100 Bolzano-Bozen, Italy*

ABSTRACT:
Soundscape research on indoor environments is emerging as a topic to be addressed for the design of supportive, healthier, and more comfortable spaces. Only a few studies so far addressed the context of educational buildings, mainly focusing on high schools and universities. This pilot study uses questionnaires based on pictorial scales to investigate the indoor soundscape of classrooms for primary school children ($n = 130$; 8–10 years old). Perceived loudness and the affective dimensions of pleasantness and arousal were explored. Besides the actual soundscape, the children's ideal soundscape was investigated as well. The results of the study indicate that the most frequent sounds in classrooms are generated by the students themselves (voices, movements) followed by the traffic. The urban context of the school modulates the children's perception when windows are open to ensure natural ventilation. Pleasantness is associated with students' age, perceived loudness, and frequency of children's voices in nearby classrooms. The frequency of hearing indoor sounds (children's voices) and sirens affects students' arousal. Our results indicate that children at school are mostly exposed to unpleasant sounds, whereas their preferred ones are music and nature-related ones. The findings have implications for the design of positive and inclusive learning environments. https://doi.org/10.1121/10.0020833

(Received 3 April 2023; revised 10 August 2023; accepted 14 August 2023; published online 20 September 2023)

[Editor: Cynthia Tarlao] Pages: 1813–1826

I. INTRODUCTION

Students spend about 5.5 hrs/day at school (OECD, 2019), learning in their classrooms. This time at school is of critical importance for the acquisition of new knowledge and skills, as well as for the children's social and emotional development, and well-being. Indeed, the school climate shapes the quality of the interactions between the students and the teachers and is predictive of the students' outcomes across the academic, behavioral, and psychological domains (Wang and Degol, 2016). The concept of school climate is multidimensional and includes the domains of academic climate (i.e., how teaching and learning are promoted in the school), community (i.e., interactions among people in the school), safety, and institutional environment (i.e., the physical and sensory qualities of the learning space—indoor environmental quality, among the others). Concerning the latter, four main aspects concur to the environmental quality of an indoor space: acoustical, thermal, indoor air, and visual quality; with acoustics, smells, and lighting playing a crucial role in determining the students' perception of the school performance. For instance, Bluyssen *et al.* (2018) report that among children 8–12 years old evaluating health and comfort in their classrooms, 87% were bothered by noise, 63% by smells, 42% by sunlight when shining, 35% didn't like the temperature in the classroom (too cold or too warm), and 34% experienced temperature changes.

It is long known that learning in classrooms with challenging acoustic conditions (high background noise levels and/or too long reverberation) results in lower perceived well-being and happiness (Astolfi *et al.*, 2019), a decrease in concentration, an increase in annoyance (Massonnié *et al.*, 2022a), an increase in effort (Prodi and Visentin, 2015; 2022) with cascading effects on performance of the task at hand (Prodi *et al.*, 2021), development of cognitive skills (Klatte *et al.*, 2013), and longer-term learning and academic achievements (Clark and Paunovic, 2018; Thompson *et al.*, 2022). Additionally, exposure to background noise alters the linguistic patterns of students, hindering complex conversational interaction and collaborative learning (McKellin *et al.*, 2011), and influences the students' behavior (D'Orazio *et al.*, 2020). The effect is so large that the World Health Organization has included cognitive impairment as a critical health outcome of environmental noise exposure for children (WHO, 2018). On these premises, standards and technical norms have been issued (Mealings, 2016) whose aim is to reduce noise as much as possible inside the classrooms and to ensure good speech production/reception by controlling relevant acoustic parameters (e.g., reverberation time, clarity of speech C50, signal-to-noise ratio SNR).

However, by considering sounds merely as environmental stressors that have to be removed to create spaces conducive to learning, we are overlooking the possibility that

[a)]This paper is part of a special issue on Advances in Soundscape: Emerging Trends and Challenges in Research and Practice.
[b)]Also at: Institute for Renewable Energy, Eurac Research, Via A. Volta/A. Volta Straße 13/A, 39100 Bolzano-Bozen, Italy.
[c)]Email: chiara.visentin@eurac.edu
[d)]Also at: Department of Civil, Environmental and Mechanical Engineering, University of Trento, Via Mesiano 77, 38123 Trento, Italy.

some sounds in the classroom might be actually "wanted" by the students and contribute to creating a positive school climate, similar to what has been argued recently in the literature on the role and potential of sounds of preference on occupants of residential buildings (Torresin *et al.*, 2019b). For instance, nature-related sounds (water streams and birds chirping, in particular) were found to have a beneficial effect on students, promoting restoration and ensuing cognitive performance (Shu and Ma, 2019; Pellegatti *et al.*, 2023). More generally, there is increasing consensus on the need to move from a building-centered to a human-centered approach in the acoustic design of indoor spaces, in general (Torresin *et al.*, 2020b), and learning spaces, in particular (Laurìa *et al.*, 2020). This kind of approach would take into account the students' preferences and needs as regards the classroom sound environment (Hamida *et al.*, 2023), aiming to achieve positively perceived indoor environments (Torresin *et al.*, 2019a), and consequently, promote well-being in its most comprehensive definition (cognitive, physical, psychological, and social; OECD, 2019).

Soundscape is defined by the ISO 12913-1 standard (ISO12913-1, 2014) as the "acoustic environment as perceived and/or understood by a person or people in context." The context is intended as the interrelation between the person, the activity, and the place, meaning that depending on the task at hand and the physical space, people will perceive, and thus, interpret and react to the sound environment differently. Therefore, instead of focusing only on the physical sound levels, soundscape considers the sound environment as a resource to be exploited in relation to its positive and restorative effects on human health and well-being (Axelsson *et al.*, 2010). Soundscape studies have been traditionally focused on outdoor environments. For these scenarios, a circumplex model based on the principal dimensions of pleasantness and eventfulness has been proposed (Axelsson *et al.*, 2010) and standardized (ISO 12913-3, 2019), enabling the comparison of results from different studies, locations, and design interventions (Cain *et al.*, 2013; Mitchell *et al.*, 2022). On the contrary, soundscape research on indoor environments is still limited, but increasingly emerging as a topic to be addressed for the design of healthier and more comfortable indoor spaces (Torresin *et al.*, 2020b; Aletta and Astolfi, 2018). Dokmeci and Kang (2010) proposed an indoor soundscaping framework based on three main variables (sound environment, built entity, contextual experience) that, compared to the outdoor soundscape, highlights the additional role of the "architectural" part with its related factors (function, spatial organization, and indoor environment) in the perceptual assessment of confined spaces. Attempts have been made to analyze soundscapes in context for various environments, such as historical spaces (Acun and Yilmazer, 2019), open-plan offices (Jo and Jeon, 2022), and residential buildings (Torresin *et al.*, 2020a; Torresin *et al.*, 2023). For the latter context, a principal component model was proposed, based on the perceptual constructs of comfort and content (Torresin *et al.*, 2020a; Torresin *et al.*, 2021; Torresin *et al.*, 2022a).

Only a few indoor soundscape studies (eight, according to the recent review by Hamida *et al.*, 2023) addressed the context of educational buildings, concerning university libraries (Dokmeci Yorukoglu and Kang, 2016; Xiao and Aletta, 2016), classrooms and computer laboratories in high schools (Çankaya Topak and Yılmazer, 2022; Chan *et al.*, 2021), and the home environment when studying from home during the COVID-19 pandemic (Dzhambov *et al.*, 2021). These studies focused on high school and university students, used a variety of soundscape descriptors (e.g., annoyance, pleasantness, sound preferences, acoustic comfort; Aletta *et al.*, 2016), and consistently showed that the students' auditory perception is mostly linked to the context (type of lesson, or task at hand). Even less information is available for younger students, despite the greater importance of the acoustic environment of learning spaces for them compared to older students and adults, given their still-developing cognitive skills. Questionnaires were used to investigate the perception of the school environment for primary school students (Brännström *et al.*, 2017; Dockrell and Shield, 2004) and preschool children's reactions and coping strategies to noisy school environments (4–5 years old; Persson Waye *et al.*, 2013). Ma *et al.* (2022) characterized the soundscape perception of preschool children, but, to the best of the authors' knowledge, no study addressed the topic of primary-school classroom acoustics by using a soundscape approach.

It is worth noticing that whereas standardized tools for assessing outdoor (and indoor) soundscape have been developed and primarily used with adults, standardized data collection methods are not available when evaluating soundscape from a child's perspective. Methods employed in the literature to assess children's perception of the acoustic environment are structured interviews and focus groups, followed by qualitative content analysis (Dellve *et al.*, 2013; McAllister *et al.*, 2019), or questionnaires, most often using non-verbal rating systems to overcome the children's limited linguistic skills (Shu and Ma, 2019; Persson Waye *et al.*, 2013; Estévez-Mauriz *et al.*, 2020; McManis *et al.*, 2001). Moreover, it is not clear whether the indoor soundscape perception model recently developed for residential buildings and adults (Torresin *et al.*, 2020a) can be directly applied to a different indoor space and context, and young children, in particular. Indeed, if adults respond affectively to the environment, according to the two dimensions of valence and arousal, children tend to describe emotions primarily in terms of valence (Posner *et al.*, 2005). Given that adults are not used to communicating about sounds as about visual aspects, as they have a limited sound-related vocabulary (Dubois, 2000; Guastavino, 2007; Davies *et al.*, 2013), it might be that children have less cognitive capacity to understand environmental stressors (Stansfeld *et al.*, 2000) and report on affective states (Posner *et al.*, 2005), together with an even more limited vocabulary. It is thus fundamental to use concepts and dimensions that match children's own vocabulary.

In summary, a few attempts have been made to apply the soundscape concept to the indoor environment of learning spaces. Studies were conducted for older students (> 14 years old), using a variety of perceptual attributes and dimensions. This work is a pilot study to investigate the indoor soundscape of classrooms for primary school students. A non-verbal instrument developed to study the emotional response to a wide range of perceptual and symbolic stimuli, such as pictures or sounds (Bradley and Lang, 1994), was used in the experiment. The assessment is based on three factors: valence (perceived pleasantness), arousal (level of excitement arising from the stimulus), and dominance (the ability of the stimulus to capture attention). Although the arousal dimension is not as pronounced in children as in adults, it was maintained because arousal and mood might represent pathways that link sound stimuli to performance outcomes (as in the case of the "Mozart effect"; Thompson *et al.*, 2001). A pictorial scale [five or nine figures; Self-Assessment Manikin (SAM)] is available for each dimension, with facial expressions or body reactions used to represent the emotion. In addition to assessing the "actual soundscape" (i.e., the sound environment that children experience in real life in classrooms), this study aimed to explore the characteristics of the "ideal soundscape" (i.e., the sounds that children would like to hear in the optimal sound scenario; Guastavino, 2006; Torresin *et al.*, 2022b). Indeed, to understand whether and how preferred sounds may impact students' well-being and cognitive performance, it is necessary to characterize what the ideal soundscape is in students' minds.

The research questions addressed in the study were as follows:

(i) How do primary school children perceive the sound environment of their classroom, according to the three perceptual dimensions of perceived loudness, pleasantness, and arousal?
(ii) What are the factors (person-related, acoustic, perceptual acoustic) influencing the dimensions of pleasantness and arousal for children in their classrooms?
(iii) What are the sounds composing the ideal soundscape of a classroom, according to the children themselves?

II. MATERIALS AND METHODS

A. Questionnaires

The questionnaire was designed to evaluate children's subjective perception of the actual sound environment of their classroom and investigate their ideal soundscape. It was implemented in Google Forms (https://www.google.com//forms/about/) and completed online using tablets. Only closed-ended questions were included. The children responded to the questionnaire in their classrooms, during a 1-hr session in the morning school hours, under the supervision of their teacher and two researchers who provided help and clarifications in case of need.

The questionnaire consisted of four sections (see supplementary material for the detailed questions).[1] The first section included four items to collect demographic information (gender, age, language spoken at home, and placement in the classroom). Moreover, it assessed the noise sensitivity of the children through the reduced Italian version of Weinstein's Noise Sensitivity Scale (Senese *et al.*, 2012).

In the second section, perceived loudness and the children's affective reaction to the sound environment of their classroom were measured. In the absence of a model of affective response to classrooms' soundscapes, we felt it would be sensible to collect information by analogy as per the recommendations of ISO/TS 12913-2 (ISO 12913-2, 2019), where the assessment of eventfulness (or content) is replaced with the assessment of arousal—constructs that are assumed to be positively related in the literature (Axelsson *et al.*, 2010). Compared with the ISO technical specification, non-verbal scales (SAM) (Bradley and Lang, 1994) were employed. Specifically, they were asked: "*How would you describe the sounds in your classroom when doing a test*?" Among the different everyday situations that students experience in their classroom, we chose to target "doing a test," since it is a visually presented cognitive activity that does not imply an additional conflict between the necessity of listening to the teacher's message and the presence of sounds in the classroom.

The three dimensions of overall perceived loudness, pleasantness, and arousal were assessed on pictorial 9-point scales (Fig. 1). It should be noticed that the scale originally used by Bradley and Lang (1994) to assess the dominance/perceived control construct, consisting of figures of different sizes, was used here for an assessment of the overall perceived loudness of the sound environment, in analogy to what was done by Estévez-Mauriz *et al.* (2020), where the same scale was used to assess the perceived dominance of different types of sound sources. For the sake of clarity, the scales were introduced verbally to the students and included verbal anchors at the scale extremities. The evaluation was repeated two times, concerning the classroom with the windows open or closed.

The third section assessed the frequency of occurrence (*How often do you hear the following sound sources when you are in your classroom doing a test?*) and pleasantness (*How would you describe the following sound sources?*) of specific noise sources. The following sources were included, based on a previous survey administered to students of similar age (Dockrell and Shield, 2004): cars, motorcycles, sirens, trains, teachers' voices from adjacent classrooms, children's voices from adjacent classrooms, chairs or desks scraping upstairs, people talking and/moving in the corridor, children's chatting in the classroom, chairs or desks scraping in the classroom, objects moved or dropped in the classroom. The evaluations referred to the classroom with the door and the windows closed and were given by using 9-point SAM scales. As the evaluation was made with the windows closed, other external sounds that might instead be audible with the windows open (e.g., birds chirping) were not included. For the evaluation of the frequency of occurrence, the same graphical scale as for the assessment of perceived loudness was used [Fig. 1(a)] with the verbal anchors modified to "never" and "always." For the evaluation of pleasantness, the scale shown in Fig. 1(b) was used.

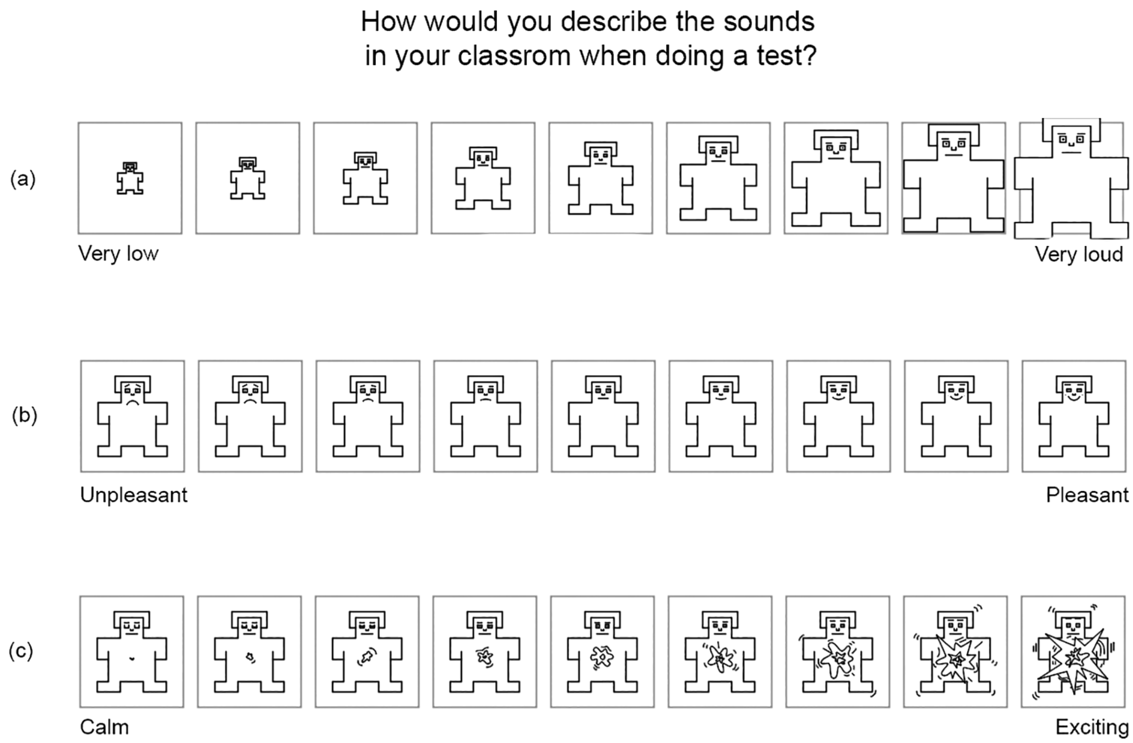

FIG. 1. Pictorial scales used for assessing perceived loudness and the affective responses to the classroom sound environment: (a) perceived loudness, (b) pleasantness, (c) arousal (after Bradley and Lang, 1994).

Finally, in the fourth section, information about the children's ideal soundscape during lessons was collected. Specifically, they were asked to rate how much they would like to hear specific sound sources on a 9-point SAM scale [from "a little" to "a lot," see Fig. 1(a)]. The following sound sources were selected: traffic (cars, motorcycles, bicycles), anthropic sounds from the outdoors (e.g., people talking or laughing, steps), children's voices from the corridor, chatting noise in the classroom, natural sounds (e.g., birds' chirping, wind, rain), and music. The sources were the same as those included in the actual soundscape, with the addition of natural sounds and music that are reported in the literature to characterize ideal soundscapes (Axelsson *et al.*, 2010; Torresin *et al.*, 2020a; Torresin *et al.*, 2022b).

B. Schools and classrooms

Three schools were involved in the project. The schools belonged to distinct urban contexts, namely the historic city center (school A, classrooms A1–A4), modern city (school B, classrooms B1–B4), and outskirts (school C, classrooms C1–C2). In the first case, all the classrooms directly faced local roads with low volumes of traffic (e.g., isolated car passages could be identified) and high presence of anthropogenic noise (e.g., people walking on the pavement and chatting). School B was located at the corner of two local streets, facing a parking lot and a small local street market. Three of the classrooms were exposed to a low-traffic street, with a row of trees partially shading their windows. Differently, the windows of the fourth classroom (B3), which was located on the ground floor of the school, faced directly the second street and the school playground. In the third school (i.e., school C), the two classrooms faced a large green courtyard, separating the school from a low-traffic, local street. Only the classrooms of the third school had an acoustically treated ceiling (see supplementary material for further information on classroom environments, e.g., dimensions, volume, occupancy).[1]

In each classroom, acoustic measurements were performed in unoccupied conditions outside school hours, with $\frac{1}{2}$ in. microphones (PCB model 377B02, PCB Piezotronics, Depew, NY) connected to a multi-channel measurement system (Synus Soundbook MK2, Spectra s.r.l., Monza Brianza, Italy). The background noise level ($L_{A,eq}$) was measured at three positions inside the classroom (height: 1.2 m, 2 min acquisitions) with the door and windows closed. Reverberation time (T30) and clarity (C50) were measured according to ISO 3382-2 (ISO 3382-2, 2008) using a wooden clapper as a sound source (Astolfi *et al.*, 2019). Source and receiver positions were selected following the recommendations of the Italian standard on classroom acoustics UNI 11532-2 (UNI 11532-2, 2020). In particular, the four receiver positions (R1–R4) were located in the area usually occupied by the students, in-axis with the sound source (R1: seating position closer to the source; R2: seating position in the center of the audience area; R3: seating position further from the source), and in the most unfavorable position (R4: seating position further from the sound source and closer to a background noise source). Table I reports the acoustic parameters measured in the

TABLE I. Acoustic parameters measured in the 10 classrooms in unoccupied conditions: background noise with windows closed ($L_{A,eq}$), reverberation time T30, and clarity C50. Each classroom location inside the school building and characteristics of the external context are also reported.

School	Classroom	$L_{A,eq}$ (dB)	T30 (s)	C50 (dB)	Location in the school building	External context
A	A1	44.8	1.18	−0.4	First floor	Local, low-traffic street
	A2	47.9	1.58	−0.3	Ground floor	Local, low-traffic street
	A3	37.6	1.14	0.15	First floor	Local, low-traffic street
	A4	44.6	1.18	−0.4	Second floor	Local, low-traffic street
B	B1	29.4	1.57	−1.8	First floor	Quiet urban context
	B2	29.9	1.61	−1.2	Ground floor	Quiet urban context
	B3	33.7	1.50	−1.3	Ground floor	Local street/playground
	B4	33.2	1.82	−3.2	First floor	Quiet urban context
C	C1	30.8	1.03	1.2	First floor	Green courtyard
	C2	30.6	1.04	1.2	First floor	Green courtyard

classrooms, obtained by first calculating a single value for each position (frequency average—T30: 0.5–1 kHz; C50: 0.5–2 kHz) and then, arithmetically averaging the values at the four positions. The reverberation time measured in the classrooms was corrected to consider an 80% occupancy and compared to the reference values defined in the UNI 11532-2 standard for category A2 (classrooms). It was found that in all the classrooms, T30 was higher than the reference value for the frequency range 125–4000 Hz. The parameter C50 was compared to the reference value of ≥ 2 dB defined in the UNI 11532-2 for classrooms smaller than 250 m^3 (unoccupied conditions), finding that in none of the classrooms it complied with the normative requirement. Finally, as concerns the background noise (composed by sounds from the outdoors and the heating, ventilation, and air conditioning system), it was lower than the value set by the Italian standard [38 dB(A)] only in the classrooms of schools B and C.

C. Participants

The questionnaire was administered to 143 students from 10 classes (grades 3–5) in three primary schools in Ferrara, Italy, during spring 2021. Thirteen students were excluded from the data analysis because of cognitive or hearing deficits, certified by the school administration (n = 1), or classified as outliers after a preliminary dataset check (see Sec. II D). The final sample included 130 children, whose characteristics are reported in Table II.

D. Data analysis

The statistical analyses were carried out with R (version 4.2.2; R Core Team, 2023). For the analyses, the 9-point scale ratings were converted on a scale from –1 to 1. Significant differences between the children's subjective evaluations were assessed using Kruskal–Wallis and pairwise Wilcoxon tests, given the ordinal nature of the pictorial scales. The results of the pairwise tests were adjusted with Bonferroni correction in the case of multiple comparisons.

To answer the second research question, two linear models were created, analyzing the effect of person-related (grade, gender, self-rated noise sensitivity), acoustic ($L_{A,eq}$, T30, and C50), and perceptual acoustic factors (perceived loudness, frequency of the sound sources) on the dimensions of pleasantness and arousal. The three categories were selected among those identified by Torresin *et al.* (2019a) as influencing the perception in indoor residential buildings, in the absence of categories specific to learning environments. Reverberation time and C50 were included given their relevance for the acoustic design of classrooms. The three perceptual dimensions referred to the closed-windows condition. A stepwise procedure was used to derive the best-fit model, based on the minimization of the model AIC (Akaike's information criterion). Outliers and influential data points (n = 12) were removed from the dataset based on the calculation of Cooke's distance for each model. In Sec. III A 1, only the results referring to the best-fitting models are reported.

III. RESULTS

A. Perception of the classroom sound environment with closed windows

The distribution of the frequency of occurrence of different sound sources in the classroom and the corresponding pleasantness is shown in Fig. 2 and in Table III (where the

TABLE II. Characteristics of the final sample of participants, by grade.

Classroom	Grade	N (female)	Age (standard deviation)
B1	III	8(3)	8.3(0.5)
B2	III	9(6)	8.1(0.3)
	III	17(9)	8.2(0.4)
A1	IV	12(8)	9.8(0.4)
A2	IV	14(7)	9.9(0.3)
B3	IV	13(5)	9.4(0.5)
B4	IV	13(7)	9.2(0.4)
	IV	52(27)	9.6(0.5)
A3	V	11(5)	10.9(0.3)
A4	V	15(7)	10.9(0.3)
C1	V	18(9)	10.3(0.5)
C2	V	17(7)	10.2(0.6)
	V	61(28)	10.5(0.5)

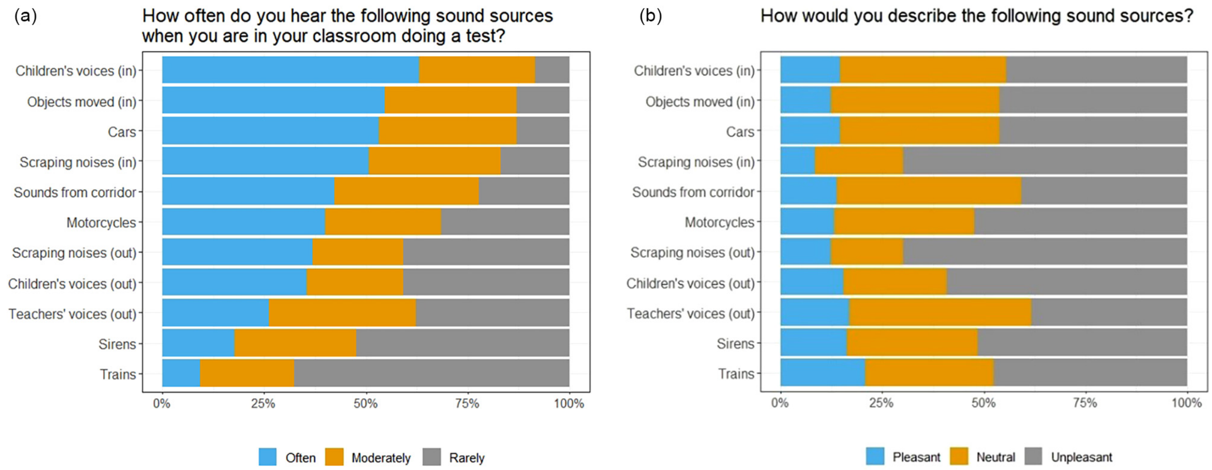

FIG. 2. (Color online) Frequency distribution of the ratings of frequency of occurrence (a) and pleasantness (b) for different sound sources. The evaluation refers to the classroom with the door and the windows closed. For data visualization, the ratings on the 9-point scale were grouped as follows: 1–3 (rarely/unpleasant), 4–6 (moderately/neutral), and 7–9 (often/pleasant). Sound sources could be either inside the classroom (in), or outside the classroom (out).

sound sources are grouped into three categories according to their position relative to the classroom).

The sound environment in the classroom with the windows closed was reported to be dominated by the sounds generated by the children themselves: students talking in the classroom, objects being moved or falling, and, to a lesser extent, desks or chairs scraping on the floor. Traffic from motor vehicles was also indicated as one of the most frequent sounds heard during lessons, followed by sounds generated inside the school but outside the classroom (e.g., voices and movements from adjacent spaces).

As concerns the pleasantness dimension, all the sound sources were perceived as being mostly unpleasant (pleasant ratings were always smaller than 20%). The most unpleasant sounds were those related to the scraping of desks and chairs (both inside the classroom and from the classrooms above) and the children's voices from adjacent classrooms, followed by the sounds of motorcycles and sirens. No correlation was found between the ratings of frequency of occurrence and pleasantness [repeated measurements correlation: $r(1299) = -0.04$, $p = 0.14$].

TABLE III. Perceived frequency of occurrence and pleasantness of the three groups of sound sources: sounds generated by the children inside the classroom (children's chatting, chairs or desks scraping, objects moved or dropped), sounds generated inside the school building but outside of the classroom (children's or teachers' voices from adjacent classrooms, chairs or desks scraping upstairs, people talking and/moving in the corridor), and sounds generated outside the school (cars, motorcycles, sirens, trains).

	Sounds generated by the children inside the classroom (%)	Sounds generated inside the school building but outside of the classroom (%)	Sounds from the outside (%)
Perceived frequency	46.2	29.0	24.7
Pleasant	11.8	14.6	16.2
Neutral	34.6	33.3	34.4
Unpleasant	53.6	52.1	49.4

1. Perception of the classroom sound environment: Differences between closed and open windows

The classroom sound environment was assessed by the students in terms of perceived loudness, pleasantness, and arousal in two conditions: closed and open windows. The results are reported in Table IV.

The presence of differences in perceived loudness, pleasantness, and arousal in the classrooms with windows open or closed was first tested by pooling all the classrooms together, irrespective of the urban context. Results indicated a significant increase in perceived loudness when the windows were open compared to the condition with windows closed. The evaluations of pleasantness and arousal were not significantly different between the two conditions.

Affective responses to the classroom sound environment were then represented in the bi-dimensional perceptual space defined by pleasantness and arousal, by considering every classroom separately. In Fig. 3, each point represents the assessment of a classroom (median value of each attribute calculated over the students of the corresponding class), with reference to the two conditions (windows closed or windows open).

The bi-dimensional representation allowed to divide the classrooms into three groups based on the change in pleasantness with windows open: G1 (decrease in pleasantness; classrooms A1, A2, A3, B3; sample size: 50 students), G2 (no changes in pleasantness; classrooms A4, C1, C2; sample size: 50 students), and G3 (increase in pleasantness; classrooms B1, B2, B4; sample size: 30 students). Figure 4 shows for each group an in-depth visualization of the distribution of soundscape assessments (50th percentile contours together with the bivariate distributions of the two conditions; Mitchell *et al.*, 2022). This visualization allows for representing the individual variation in the perception of the

TABLE IV. Median values and interquartile ranges (in parenthesis) for the perceptual dimensions, in the conditions with open and closed windows.

Variable	Windows closed	Windows open	Difference
Perceived loudness	−0.25(0.75)	0.25(0.75)	W = 10 971, $p < 0.001$
Pleasantness	0(0.25)	0(0.25)	W = 8180, $p = 0.65$
Arousal	−0.25(0.5)	0(0.25)	W = 9545, $p =$ 0.07

soundscape of a space (i.e., the degree of agreement about the soundscape perception among the children) and the general shape of the soundscape within the space. Table V shows the aggregated data for each group.

Statistical analysis was first run to compare the perceptual evaluations in the open- and closed-windows condition for each group. The results indicated that the graphical difference highlighted a tendency in the data that was not substantiated by statistical significance for any of the three groups, concerning pleasantness and arousal (all *p*s > 0.21). Only the increase in arousal for group G1 was statistically significant (W = 1560, $p = 0.015$). Conversely, perceived loudness showed a significant increase from the condition with windows closed to the condition with windows open for both G1 (W = 1848, $p < 0.001$) and G2 (W = 1557, $p = 0.033$). No significant difference in perceived loudness was found for G3 ($p = 0.44$).

The perceptual evaluations of the three groups were then directly compared in the two conditions. No significant differences between the three groups were found in the perceptual dimensions rated in the closed-windows condition (all *p*s > 0.11). On the contrary, in the open-window condition, in G1 perceived loudness and arousal were significantly higher than in the other two groups. Likewise, pleasantness was significantly lower in group G1 compared to the other two groups.

Finally, differences between the frequency of the sound sources (closed-windows condition) rated by the three groups were analyzed. Results indicated that children having lessons in the classrooms of group G1 heard more frequently

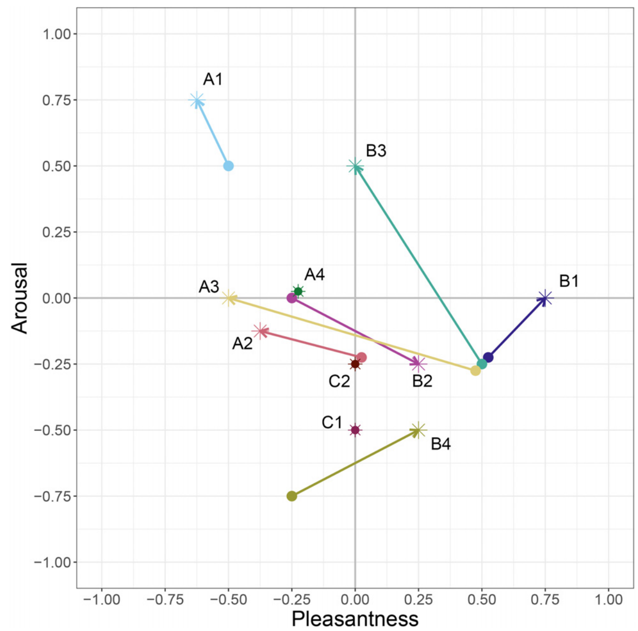

FIG. 3. (Color online) Projection of the affective responses to the classroom sound environment onto the bi-dimensional space defined by the pleasantness–arousal dimensions. Points refer to the median assessment of a class, with reference to the condition with windows closed (circles) or open (asterisks). The codes and characteristics of the classrooms can be found in Table I.

sounds from outside the classroom compared to the other two groups. On the contrary, they were less exposed to the chatter noise of the children inside the classroom.

B. Perceptual dimensions of pleasantness and arousal: Influencing factors

Regression analyses were conducted to explore whether person-related, acoustic, and perceptual acoustics factors predict the children's perception in classrooms in terms of pleasantness and arousal. Table VI shows the results for the linear model minimizing the AIC metric for the dimension of pleasantness (closed-window condition). All the acoustic/personal/perceptual acoustic factors that are not reported in

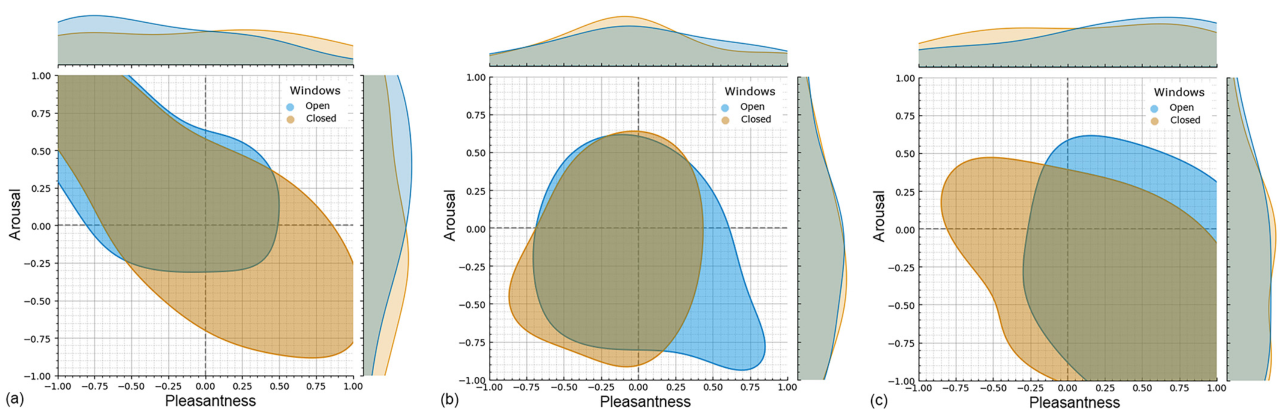

FIG. 4. (Color online) Classroom soundscape perception as a probabilistic distribution over the bi-dimensional space of pleasantness and arousal. The 50th percentile contour is represented, and the perception in the classroom with windows open or closed is compared. (a) G1: group of four four classes showing a tendency to decrease in pleasantness when windows are open compared to the closed-window condition, (b) G2: group of three classes experiencing no changes in pleasantness when the average rating of the students was considered, (c) G3: group of four classes tending to increase in pleasantness.

TABLE V. Median values and interquartile ranges (in parenthesis) for the perceptual dimensions, in the conditions with open and closed windows for the groups G1–G3. In the lower part of the table, the perceived frequencies of occurrence (median and interquartile range) for the sound sources are reported, for the three groups.

Condition	Variable	Group G1	Group G2	Group G3	Differences
Windows closed	Perceived loudness	−0.25(0.75)	−0.25(0.69)	−0.125(0.44)	—
	Pleasantness	0(1.25)	0(0.50)	0.125(1.25)	—
	Arousal	−0.25(1.00)	−0.25(0.69)	−0.25(1.00)	—
Windows open	Perceived loudness	0.5(0.50)	0(0.50)	0(1.00)	G1 > G2, $p < 0.001$ G1 > G3, $p = 0.004$
	Pleasantness	−0.5(0.94)	0(0.75)	0.25(1.00)	G1 < G2, $p = 0.004$ G1 < G3, $p < 0.001$
	Arousal	0.25(0.75)	−0.25(0.88)	−0.375(1.19)	G1 > G2, $p < 0.001$ G1 > G3, $p < 0.001$

Perceived frequency of occurrence of the sound sources (windows closed)

Sound source	Group G1	Group G2	Group G3	Differences
Cars	8.0(3.0)	6.0(3.0)	5.0(3.5)	G1 > G2, $p < 0.001$ G1 > G3, $p < 0.001$
Motorcycles	7.0(4.0)	5.0(4.0)	4.0(5.0)	G1 > G2, $p = 0.045$
Sirens	4.0(4.5)	3.0(3.0)	4.0(3.0)	—
Trains	1.5(2.0)	2.0(3.0)	4.0(3.0)	—
Teachers' voices (out)	5.0(4.0)	3.0(4.0)	5.0(2.5)	—
Children's voices (out)	7.0(3.75)	5.0(5.0)	3.0(3.5)	G1 > G2, $p = 0.002$
Scraping noises (out)	7.5(4.0)	3.0(5.0)	1.0(4.0)	G1 > G2, $p < 0.001$ G1 > G3, $p < 0.001$
Sounds from corridor	6.0(4.0)	6.0(5.0)	5.0(3.0)	—
Children's voices (in)	7.0(5.0)	6.0(3.0)	9.0(2.0)	G1 > G3, $p = 0.035$
Scraping noises (in)	7.0(5.0)	7.0(3.0)	6.0(3.5)	—
Objects moved (in)	7.5(3.0)	7.0(3.0)	6.0(4.0)	—

Table VI had a non-significant effect on the perceptual dimension. The analysis indicated a significant effect of the grade, perceived loudness (unoccupied conditions), and perceived frequency of occurrence of children's voices from nearby classrooms. An increase in perceived loudness corresponds to a significant decrease in pleasantness, whereas the frequency of children's voices outside the classroom is positively related to pleasantness. Pairwise comparisons were run to analyze the significant effect of grade and showed that the third-graders perceived a more pleasant classroom sound environment compared with the fourth-graders (III > IV: median difference $= 0.46$, $t = 3.04$, $p = 0.009$). The proportion of variance explained by the model is 17.2%.

The results of the linear model for arousal (closed-windows conditions) are reported in the lower panel of Table VI. The analysis indicated a significant effect of perceived loudness, reverberation time (unoccupied conditions), and perceived frequency of occurrence of sirens, trains, and children's voices from nearby classrooms. An increase in perceived loudness, frequency of sirens, and children's voices corresponds to a significant increase in perceived arousal. Conversely, a decrease in the measured reverberation time and frequency of trains corresponds to an increase in arousal. The model explained 40.9% of the data variance.

C. Ideal classroom soundscape

The frequency distribution of the sound sources that children would like to hear in their classrooms is shown in Fig. 5. The ideal sound environment for our sample of children is free from anthropic sounds, either directly generated by people (e.g., voices) or related to vehicles. On the contrary, music and sounds related to nature are favored by children.

Correlation analyses (overall, by grade, and by school) were performed to understand whether the perception of the actual soundscape had an influence on the evaluation of the ideal soundscape. No significant correlation was found between the two evaluations.

IV. DISCUSSION

This study aimed to investigate the classroom soundscape with reference to primary school students (8–10 years old). In the absence of previous studies on the indoor soundscape for young children and of a model for affective responses in this specific context, we asked the children to assess their perception of the actual sound environment based on the following dimensions: pleasantness, arousal, and perceived loudness. The "ideal" soundscape was also explored to get insight into children's *desiderata* and take

TABLE VI. Linear models for pleasantness (upper panel) and arousal (lower panel). Both dimensions refer to the sound environment of the classroom with windows closed. Significance codes for the *p*-values: [a]< 0.001, [b]< 0.01, [c]< 0.05.

Predictor	Estimate	Standard error	t-value	*p*-value
	Pleasantness			
(Intercept)	0.19	0.12	1.53	0.13
Grade (4)	−0.46	0.15	−3.04	0.003[b]
Grade (5)	−0.24	0.15	−1.67	0.10
Perceived loudness	−0.5	0.10	−4.45	<0.001[a]
Frequency: children's voices in nearby classrooms	0.17	0.07	2.51	0.013[c]
	Arousal			
(Intercept)	0.56	0.21	2.69	<0.001[a]
Perceived loudness	0.52	0.08	6.18	<0.001[a]
T30 (s)	−0.51	0.15	−3.36	0.001[b]
Frequency: sirens	0.32	0.08	3.77	<0.001[a]
Frequency: trains	−0.27	0.08	−3.36	0.001[b]
Frequency: children's voices in nearby classrooms	0.14	0.06	2.31	0.022[c]
Frequency: chairs scraping in classrooms above	0.10	0.06	1.74	0.084

the first steps toward the use of sounds as a means to promote a positive school climate.

A. Actual soundscape of the classroom

The results of the study suggest that children are exposed at school to unpleasant sounds (Fig. 2). As regards specific sound sources heard inside the classroom, sounds generated by the children themselves (voices, objects, or furniture being moved) occur more often than sounds coming from outside. The result extends literature findindgs, which were focused on older students, to children aged 8 to 10 (9–16 years old, Brännström *et al.*, 2017; secondary school, Astolfi and Pellerey, 2008; university, Kennedy *et al.*, 2006). Given its predominance in the classroom sound environment, this type of noise is thus expected to have the greatest impact on children's well-being and learning. Indeed, compared to sounds from outside the classroom, it is generally rated as the most annoying (Boman and Enmarker, 2004), the most disturbing (Astolfi and Pellerey, 2008), and the most detrimental to task performance (Visentin *et al.*, 2023) and academic outcomes (Dockrell and Shield, 2004).

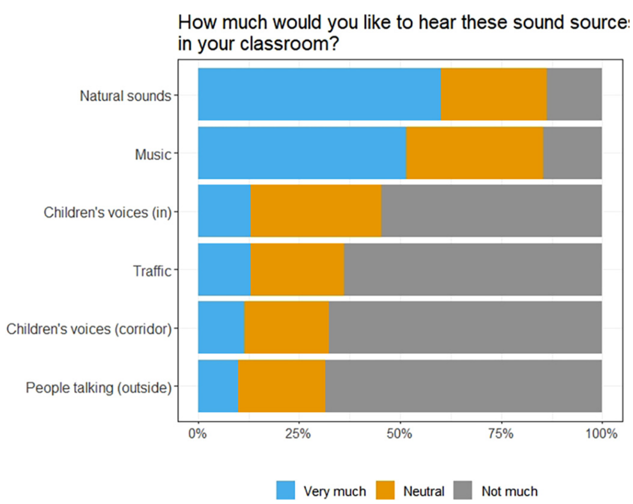

FIG. 5. (Color online) Frequency distribution of the children's ratings with reference to their ideal classroom soundscape. For data visualization, the ratings on the 9-point scale were grouped as follows: 1–3 (not much), 4–6 (neutral), 7–9 (very much).

Concerning sounds from outside the classroom, we found that road traffic (cars and motorcycles) is the most frequent source, whereas the frequency of occurrence of sounds generated outside of the classroom but inside the school building (e.g., voices and movements from nearby spaces) is generally lower. The former result aligns closely with previous literature for children of similar age (Brännström *et al.*, 2017; Dockrell and Shield, 2004) indicating the importance of the school location within the urban context for the students' well-being.

The importance of the school location gains even more relevance when the cross-modal effect of acoustics and indoor air quality (IAQ) on the indoor soundscape is considered. All the schools participating in our experiment were naturally ventilated buildings, in which proper IAQ is ensured by opening windows. It should be noted that the importance of ventilation in schools has become even more relevant since the Covid-19 outbreak, forcing an improvement in classroom ventilation to prevent the spread of the virus. The simple act of opening the windows changes the sound environment of the classroom, leading the students to greater exposure to external sound sources and consequently affecting the indoor soundscape (Pellegatti *et al.*, 2023). In this sense, the urban context of the school (thus, being located in areas more or less exposed to traffic noise, according to our findings) might moderate the children's affective responses each time windows are opened to ensure proper ventilation.

Our results show that classroom soundscape can be traced back not only to the school context at the urban scale but also to a more granular scale where the location of the classroom within the school matters. In particular, children attending lessons in classrooms with an outdoor environment more characterized by the sounds of motor vehicles experience a greater difference in perceived loudness between the two conditions of windows closed and open, compared to children having lessons in classrooms less exposed to traffic noise. It is worth noticing that children's affective responses are influenced by the specific orientation of the classroom windows, and seemingly by the location of the classroom in the school building more than by the urban context. This is the case of classroom B3 which belongs to a school located in a quiet neighborhood of the city, but that elicits the same affective responses of classrooms located in the city center (thus more exposed to traffic), due to its location (ground floor) and exposure (directly facing the street). Likewise, classroom A4, despite being located in the city center, elicits the same responses as the classrooms of school C, located on the outskirts and facing a green courtyard. It might be speculated that being located on the second floor of the school building prompts in the students a sense of "detachment" from the outdoor environment thus eliciting more positive responses.

In addition to perceived loudness, the urban context also elicits differences in pleasantness and arousal when windows are opened. Specifically, students in classrooms with an outdoor environment more characterized by traffic noise will experience a decrease in pleasantness and an increase in arousal when opening the windows. On the contrary, the same pleasantness or an increased one (same/reduced arousal) is elicited during natural ventilation for classrooms located in less exposed areas. It should be acknowledged that the partition of the classrooms into three groups was only based on the dimension of perceived pleasantness, but other factors (e.g., demographical or socio-cultural) might be relevant to explain the observed differences between perception with open and closed windows.

Despite this limitation, the result has implications for the selection of the best ventilation strategy to be adopted in the classroom. For instance, classrooms exposed to outdoor sound environments characterized by human-generated sounds might be equipped with mechanical ventilation, whereas children in less-exposed classrooms take advantage of a natural ventilation strategy. Moreover, natural ventilation in natural outdoor settings may even be able to improve the indoor soundscape (Torresin *et al.*, 2019b). It should be recalled that in this study, the evaluation of sound sources was carried out with closed windows. Future field campaigns in schools should also be conducted with open windows and in contexts with a gradient of natural features, to evaluate the potential of natural sounds transmitted through open windows in improving students' pleasantness and cognitive performance. The significance of natural sounds in the classroom environment was evident from the students' responses regarding their ideal soundscape. This finding further strengthens the notion that these sounds could contribute to creating a positive sound environment (for a more extensive discussion, refer to Sec. IV C).

B. Factors influencing the classroom soundscape

The final model with the best fit for pleasantness suggested that children's ratings were negatively related to overall perceived loudness, and positively related to the frequency of children's voices from adjacent classrooms. That is to say that a positive perceptual outcome is seemingly elicited in quieter classrooms, in which some anthropogenic sounds are still present. It might be speculated that hearing the voices of the children in other classrooms promotes pleasantness by enhancing children's sense of inclusion and community, but dedicated studies are needed to test this hypothesis. Given the low proportion of variance explained by the model (17%), it might be hypothesized that the perceptual acoustic factors used in our study (frequency of occurrence) were not decisive for the pleasantness assessment of the children, which could instead be based on other factors. For instance, asking them to rate the perceived loudness of the single sound sources instead of frequency (as per ISO/TS 12913-2), and using it in the regression model might result in a higher proportion of variance explained. Interestingly, perceived loudness appears to be a relevant factor in explaining pleasantness, unlike decibel-based sound levels. The results of previous soundscape studies showed that pleasantness and comfort are better explained by the loudness parameter and by the perceived dominance of individual sound sources and to a less extent by the sound level in decibels (Axelsson *et al.*, 2010; Torresin *et al.*, 2020a), which is more frequently employed in building and room acoustics assessments. Furthermore, while perceived loudness is an important aspect in explaining sound perception, the results derived from the representation of affective response in the circumplex space showed that an increase in perceived loudness (e.g., while opening windows) is not necessarily associated with a reduction in pleasantness [as in the case of the G2 group, Fig. 4(c)]. As argued in the soundscape literature (Kang *et al.*, 2016), acoustic perception is complex and highly multifactorial and it is related not only to noise levels but also to the meaning carried by sound sources, as well as to non-acoustic factors (Riedel *et al.*, 2021), such as phenomena of interaction with other sensory realms—among others—visual (Li and Lau, 2020) and olfactory (Bluyssen *et al.*, 2021). With specific reference to the indoor environment, a classification model for the soundscape factors was proposed, including, besides acoustic variables, also architectural (e.g., function, architectural properties) and contextual (e.g., psychological, demographical) factors (Erçakmak and Dökmeci Yörükoğlu, 2019). Understanding these interrelationships could guide urban planning and building design to promote student well-being on the one hand and passive ventilation strategies on the other.

The model with the best fit for arousal indicated that children's arousal increases in classrooms with high perceived loudness. It is also positively related to the frequency of occurrence of sounds related sirens and children's voice in adjacent classrooms. Both are sound sources external to the classroom and with a strong attentional capturing potential, being unexpected events, deviant from the auditory context. Interestingly, no sound sources internal to the classroom seemed to be influential for the arousal dimension, despite their higher perceived frequency. A negative relation between arousal and reverberation time was observed as well, supporting the relevance of acoustic parameters other than noise level for the indoor soundscape. It might be speculated that with longer reverberation times, sounds generated in the classroom (voices, movement) are more "blurred" and therefore have a lesser potential to capture attention, thus decreasing arousal. While the literature suggests a reduction in arousal by exposure to natural sounds (Ratcliffe, 2021; Alvarsson *et al.*, 2010), future studies should investigate the effect of these and other sound types on students' arousal, also exploring potential moderating or mediating effects on cognitive performance.

Concerning person-related factors, we found that younger children perceived the classroom sound environment as more pleasant than older children. Due to the imbalanced dataset (see also the Limitations and future research section), it cannot be excluded that the effect originates from the specific characteristics of school B, to which both classes of third-graders belonged. However, the presence of an age effect aligns with previous literature findings, which nonetheless indicate an opposite trend, with younger children reporting greater difficulties in differentiating listening contexts (Dockrell and Shield, 2004), and students in higher grades experiencing improved ease of hearing compared to younger children (Brännström *et al.*, 2017). No significant effect of the other person-related factors (gender, noise sensitivity) was found in our study. It has to be noticed that a small effect of gender, with girls being more annoyed by the noise and experiencing less ease of hearing than boys, was found by Brännström *et al.* (2017). Moreover, gender was one of the demographical factors identified by Dokmeci Yorukoglu and Kang (2017) as significantly related to the reaction and the perception of sound sources within libraries by young adults. Also, a strong association between noise sensitivity and noise annoyance is well documented for children (Massonnié *et al.*, 2022b). However, as for the findings on the age effect, it should be considered that all the literature results refer to subjective evaluations of the sound stimuli addressed in their negative connotation (e.g., annoyance) and older children. It might be that different mediation patterns for person-related factors, or even different factors, will be relevant in the case of the affective responses of younger children.

C. Ideal classroom soundscape

Concerning the ideal classroom soundscape for children, we found that nature-related sounds were highly preferred, closely followed by music. Anthropogenic sounds (voices, traffic) were the least preferred, either generated inside or outside of the classroom. These preferences seem to be of a general nature, as they are not related to the actual acoustic environment perceived by the students in their classrooms.

The children's preference for natural sounds is in line with literature suggesting that nature-related settings might facilitate stress recovery (Stress Reduction Theory; Ulrich *et al.*, 1991). Indeed, exposure of students in the classroom to natural sounds has a positive effect on comfort (mediated by the sound level; Pellegatti *et al.*, 2023) and learning performance (Luo *et al.*, 2022) and has a restorative effect on memory and attention (Shu and Ma, 2019). Also, playing some music during lessons was found to prompt benefit for children's reasoning skills, and have a calming and focusing effect for children with special educational needs (SEN) (Črnčec *et al.*, 2006).

Therefore, the children participating in our study expressed a preference for sound stimuli able to promote calmness and restoration during lessons. We did not include the "silent" (no sounds) option among the answers available to the children. However, the high preference expressed for music and natural sounds suggests that the presence of some, specific sounds in the classroom might be preferred by the children compared to a completely silent condition, which is hardly possible in the classroom. Future research might better address this specific aspect, but the results of this pilot study seem to reinforce the idea that silence (and the current approach solely based on noise control) does not always define a classroom sound environment of high quality (Aletta and Kang, 2019). This is consistent with the concept of "positive soundscapes," which may need to be either "quiet" or "vibrant" in schools, depending on the spaces, activities, and pedagogical modalities employed, and where the very concept of quietness does not exclude the presence of sound (Andringa and Lanser, 2013; Tsaligopoulos *et al.*, 2021).

D. Limitations and future research

This study has three main limitations. First, acoustical parameters were only measured in unoccupied conditions, thus reducing the predictive power of the regression models. Furthermore, the acoustic measurements took place at different times to those at which the perceptual evaluations were collected, thus potentially resulting in a mismatch between the acoustic conditions recorded and those present at the time the questionnaires were administered. Future research should examine the correlation between the children's perception and acoustical parameters measured in occupied conditions, possibly in several different contexts (e.g., frontal lesson, group work), also including psychoacoustic metrics. Other parameters, besides T30 and $L_{A,eq}$, could be considered as well. For instance, given the relevance of the children's voices as a sound source in the classroom, it might be expected that early decay time and the difference between statistical noise levels ($L_{A,10}$–$L_{A,90}$), play a role in the children's perception. Moreover, aiming for an approach blending multiple domains (Schweiker *et al.*, 2020), the outdoor sound environment, the quality of the window view, the thermal and visual environments, and the air quality should be closely monitored and characterized.

Second, this being a pilot study, the sample size was limited to 130 students, and the classes were recruited on a voluntary basis. Therefore, sample uniformity was not guaranteed throughout the study and, for instance, only fifth graders were included for school C, yielding potential confusion on the factors (grade or urban context?) determining the effects observed on the perceptual dimensions. Further studies on classroom indoor soundscape should involve a greater number of students and pay particular attention to the balancing of the sample as regards to grade, school location in the urban context, and classroom acoustic characteristics.

Third, given the low number of children with special educational needs (e.g., with hearing impairments, autism spectrum disorder, children learning in a second language), it was not possible to consider them as a separate group in the analysis. It is well known that children with SEN are differentially negatively affected by non-adequate classroom acoustic conditions compared to other learners (Dockrell and Shield, 2006; Ueno *et al.*, 2019; Jamieson *et al.*, 2018). It might as well be possible that the factors determining a positive soundscape will be different for them. Future research on indoor soundscape should specifically target this population aiming to support their well-being and design inclusive learning environments, with a sonic environment that could work for all the children in the classroom. Furthermore, classroom soundscape should be studied from the viewpoint of teachers. Similarly to the students, they spend several hours per day in the classroom, and its soundscape is a relevant factor for their well-being, and their coping and teaching strategies (Hytönen-Ng *et al.*, 2022).

Future studies shall also explore the dimensions of the perceptual space describing the students' affective response to the classroom's acoustic environment. The perceptual dimensions proposed for residential buildings (comfort and content; Torresin *et al.*, 2020a) might be applied to high school or university classrooms, thus overcoming the issues related to the affective responses of young children outlined in the Introduction and obtaining an in-depth understanding of the indoor soundscape. However, the need remains for developing a classroom indoor soundscape model tailored (both in the concepts and in the graphical form) to the younger children for which the sonic environment is a fundamental factor of well-being, with cascading consequences on school performance and future life chances.

Finally, it is important to consider that a new approach to teaching and learning is increasingly being adopted, no longer based on a teacher-centered approach, but using technology and peer collaboration as key approaches for learning. This collaborative process requires new spaces in the school (Byers *et al.*, 2014), that might even be tailored to specific areas of learning and teaching, thus forcing us to rethink the physical spaces, the role of teachers and students, and the learning style. Therefore, the soundscape assessment should not be limited to traditional classrooms but will have to be extended to these different contexts to promote a supportive sonic environment closely linked to the students' activities and teachers' needs.

V. CONCLUSIONS

In this study, the indoor soundscape of classrooms was investigated for primary school children (8–10 years old). Perceived loudness and the affective dimensions of pleasantness and arousal were explored in the experiment, by using non-verbal, pictorial scales with children.

The main findings of this pilot study are as follows:

(i) Children perceive they are exposed to unpleasant sounds at school. Sounds generated by the children themselves (voices, movements) occur more often than sounds coming from outside the classroom. The urban context of the school moderates the children's affective responses, mainly in terms of pleasantness, each time the windows are opened to ensure proper ventilation.

(ii) Pleasantness is related to students' age, perceived loudness, and the frequency of children's voices in nearby classrooms. Perceived loudness, reverberation time, and the frequency of hearing indoor sounds (e.g., children's voices and chairs in nearby classrooms) and outdoor sounds (e.g., sirens) affect students' arousal.

(iii) Children's "ideal" soundscape during lessons consists of sound stimuli promoting calm and restoration (music and natural sounds). The result reinforces the idea that future research should not solely evaluate annoying acoustic environments but focus on diverse, beneficial soundscapes as well.

Our study contributes to a better understanding of the children's perception of their classroom sonic environment. Future research is needed to establish the dimensions along which to assess the acoustic perception of primary school children, with the long-term goal to derive design suggestions for supportive and inclusive learning environments.

ACKNOWLEDGMENTS

We thank the children and the teachers of the three schools in Ferrara, Italy, for participating in the experiment. This work was funded by the project COMPRENDO from the Emilia-Romagna Region [Action POR FESR 2014–2020 – Axis 1 Action 1.2.2 (2019)] and by the project BRIC 2019 - topic ID 14 from the National Institute for Insurance against Accidents at Work, Italy. C.V. and S.T. contributed equally to this work. The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Institutional Review Board of Psychology of the University of Chieti-Pescara (Department of Psychological, Health, and Territorial Sciences; Protocol No. 22015). The study was preliminarily approved by the management of the three schools. The guardians of the children provided written informed consent for their children to participate. The data that support the findings of this study are available from the corresponding author upon reasonable request.

[1]See supplementary material at https://doi.org/10.1121/10.0020833 for the detailed questions included in the questionnaire and for further information on classroom environments.

Acun, V., and Yilmazer, S. (**2019**). "Combining Grounded Theory (GT) and Structural Equation Modelling (SEM) to analyze indoor soundscape in historical spaces," Appl. Acoust. **155**, 515–524.

Aletta, F., and Astolfi, A. (**2018**). "Soundscapes of buildings and built environments," Build. Acoust. **25**, 195–197.

Aletta, F., and Kang, J. (**2019**). "Promoting healthy and supportive acoustic environments: Going beyond the quietness," Int. J. Environ. Res. Public Health **16**, 4988.

Aletta, F., Kang, J., and Axelsson, Ö. (**2016**). "Soundscape descriptors and a conceptual framework for developing predictive soundscape models," Landsc. Urban Plan. **149**, 65–74.

Alvarsson, J. J., Wiens, S., and Nilsson, M. E. (**2010**). "Stress recovery during exposure to nature sound and environmental noise," Int. J. Environ. Res. Public Health **7**, 1036–1046.
Andringa, T., and Lanser, J. (**2013**). "How pleasant sounds promote and annoying sounds impede health: A cognitive approach," Int. J. Environ. Res. Public Health **10**, 1439–1461.
Astolfi, A., and Pellerey, F. (**2008**). "Subjective and objective assessment of acoustical and overall environmental quality in secondary school classrooms," J. Acoust. Soc. Am. **123**, 163–173.
Astolfi, A., Puglisi, G. E., Murgia, S., Minelli, G., Pellerey, F., Prato, A., and Sacco, T. (**2019**). "Influence of classroom acoustics on noise disturbance and well-being for first graders," Front. Psychol. **10**, 2736.
Axelsson, Ö., Nilsson, M. E., and Berglund, B. (**2010**). "A principal components model of soundscape perception," J. Acoust. Soc. Am. **128**, 2836–2846.
Bluyssen, P. M., Zhang, D., Kim, D. H., Eijkelenboom, A., and Ortiz-Sanchez, M. (**2021**). "First SenseLab studies with primary school children: Exposure to different environmental configurations in the experience room," Intell. Build. Int. **13**, 275–292.
Bluyssen, P. M., Zhang, D., Kurvers, S., Overtoom, M., and Ortiz-Sanchez, M. (**2018**). "Self-reported health and comfort of school children in 54 classrooms of 21 Dutch school buildings," Build. Environ. **138**, 106–123.
Boman, E., and Enmarker, I. (**2004**). "Factors affecting pupils' noise annoyance in schools: The building and testing of models," Environ. Behav. **36**, 207–228.
Bradley, M. M., and Lang, P. J. (**1994**). "Measuring emotion: The self-assessment manikin and the semantic differential," J. Behav. Ther. Exp. Psychiatr. **25**, 49–59.
Brännström, K. J., Johansson, E., Vigertsson, D., Morris, D. J., Sahlén, B., and Lyberg-Åhlander, V. (**2017**). "How children perceive the acoustic environment of their school," Noise Health **19**, 84–94.
Byers, T., Imms, W., and Hartnell-Young, E. (**2014**). "Making the case for space: The effect of learning spaces on teaching and learning," Curric. Teach. **29**, 5–19.
Cain, R., Jennings, P., and Poxon, J. (**2013**). "The development and application of the emotional dimensions of a soundscape," Appl. Acoust. **74**, 232–239.
Çankaya Topak, S., and Yılmazer, S. (**2022**). "A comparative study on indoor soundscape assessment via a mixed method: A case of the high school environment," Appl. Acoust. **189**, 108554.
Chan, Y.-N., Choy, Y.-S., To, W.-M., and Lai, T.-M. (**2021**). "Influence of classroom soundscape on learning attitude," Int. J. Instruct. **14**, 341–358.
Clark, C., and Paunovic, K. (**2018**). "WHO Environmental Noise Guidelines for the European Region: A Systematic Review on Environmental Noise and Cognition," Int. J. Environ. Res. Public Health **15**, 285.
Črnčec, R., Wilson, S. J., and Prior, M. (**2006**). "The cognitive and academic benefits of music to children: Facts and fiction," Educ. Psychol. **26**, 579–594.
Davies, W. J., Adams, M. D., Bruce, N. S., Cain, R., Carlyle, A., Cusack, P., Hall, D. A., Hume, K. I., Irwin, A., Jennings, P., Marselle, M., Plack, C. J., and Poxon, J. (**2013**). "Perception of soundscapes: An interdisciplinary approach," Appl. Acoust. **74**, 224–231.
Dellve, L., Samuelsson, L., and Waye, K. P. (**2013**). "Preschool children's experience and understanding of their soundscape," Qual. Res. Psychol. **10**, 1–13.
Dockrell, J. E., and Shield, B. (**2004**). "Children's perceptions of their acoustic environment at school and at home," J. Acoust. Soc. Am. **115**, 2964–2973.
Dockrell, J. E., and Shield, B. M. (**2006**). "Acoustical barriers in classrooms: The impact of noise on performance in the classroom," Brit. Educ. Res. J. **32**, 509–525.
Dokmeci, P. N., and Kang, J. (**2010**). "Objective parameters for acoustic comfort in enclosed spaces," in *Proceedings of 20th International Congress on Acoustics, Ica, 2010*, Sydney Australia, 23–27 August 2010.
Dokmeci Yorukoglu, P. N., and Kang, J. (**2016**). "Analysing sound environment and architectural characteristics of libraries through indoor soundscape framework," Archives Acoust. **41**, 203–212.
Dokmeci Yorukoglu, P. N., and Kang, J. (**2017**). "Development and testing of Indoor Soundscape Questionnaire for evaluating contextual experience in public spaces," Build. Acoust. **24**(4), 307–324.
D'Orazio, D., De Salvio, D., Anderlucci, L., and Garai, M. (**2020**). "Measuring the speech level and the student activity in lecture halls: Visual-vs blind-segmentation methods," Appl. Acoust. **169**, 107448.
Dubois, D. (**2000**). "Categories as acts of meaning: The case of categories in olfaction and audition," Cognitive Sci. Quart. **1**, 35–68.
Dzhambov, A. M., Lercher, P., Stoyanov, D., Petrova, N., Novakov, S., and Dimitrova, D. D. (**2021**). "University students' self-rated health in relation to perceived acoustic environment during the COVID-19 home quarantine," Int. J. Environ. Res. Public Health **18**, 2538.
Erçakmak, U. B., and Dökmeci Yörükoğlu, P. N. (**2019**). "Comparing Turkish and European noise management and soundscape policies: A proposal of indoor soundscape integration to architectural design and application," Acoustics **1**(4), 847–865.
Estévez-Mauriz, L., Forssén, J., Zachos, G., and Kropp, W. (**2020**). "Let the children listen: A first approximation to the sound environment assessment of children through a soundwalk approach," Int. J. Environ. Res. Public Health **17**, 4185.
Guastavino, C. (**2006**). "The ideal urban soundscape: Investigating the sound quality of French cities," Acta Acust. united Acust. **92**, 945–951.
Guastavino, C. (**2007**). "Categorization of environmental sounds," Can. J. Exp. Psychol. **61**, 54–63.
Hamida, A., Zhang, D., Ortiz, M. A., and Bluyssen, P. M. (**2023**). "Indicators and methods for assessing acoustical preferences and needs of students in educational buildings: A review," Appl. Acoust. **202**, 109187.
Hytönen-Ng, E., Pihlainen, K., Ng, K., and Kärnä, E. (**2022**). "Sounds of learning: Soundscapes - teacher perceptions of acoustic environments in Finland's open plan classrooms," Issues Educ. Res. **32**, 1421–1440.
ISO 12913-1:2014 (**2014**). "Acoustics–soundscape - Part 1: Definition and conceptual framework" (International Organization of Standardization, Geneva, Switzerland), https://www.iso.org/standard/52161.html. (Last viewed July 31, 2023).
ISO 12913-2:2018 (**2018**). "Acoustic–soundscape - Part 2: Data collection and reporting requirements" (International Organization of Standardization, Geneva, Switzerland), https://www.iso.org/standard/75267.html (Last viewed July 31, 2023).
ISO 12913-3:2019 (**2019**). "Acoustics–soundscape - Part 3: Data analysis" (International Organization of Standardization, Geneva, Switzerland), https://www.iso.org/standard/69864.html (Last viewed July 31, 2023).
ISO 3382-2:2008 (**2008**). "Acoustics–Measurement of room acoustic parameters – Part 2: Reverberation time in ordinary rooms" (International Organization of Standardization, Geneva, Switzerland), https://www.iso.org/standard/36201.html (Last viewed July 31, 2023).
Jamieson, J. R., Poon, B., and Zaidman-Zait, A. (**2018**). "Learning and interacting in noisy classrooms: What background noise measures and subjective teacher perceptions tell us about the challenges for students who are hard of hearing," J. Acoust. Soc. Am. **144**, 1976.
Jo, H. I., and Jeon, J. Y. (**2022**). "Influence of indoor soundscape perception based on audiovisual contents on work-related quality with preference and perceived productivity in open-plan offices," Build. Environ. **208**, 108598.
Kang, J., Aletta, F., Gjestland, T. T., Brown, L. A., Botteldooren, D., Schulte-Fortkamp, B., Lercher, P., van Kamp, I., Genuit, K., Fiebig, A., Luis Bento Coelho, J., Maffei, L., and Lavia, L. (**2016**). "Ten questions on the soundscapes of the built environment," Build. Environ. **108**, 284–294.
Kennedy, S. M., Hodgson, M., Edgett, L. D., Lamb, N., and Rempel, R. (**2006**). "Subjective assessment of listening environments in university classrooms: Perceptions of students," J. Acoust. Soc. Am. **119**, 299–309.
Klatte, M., Bergström, K., and Lachmann, T. (**2013**). "Does noise affect learning? A short review on noise effects on cognitive performance in children," Front. Psychol. **4**, 578.
Laurìa, A., Secchi, S., and Vessella, L. (**2020**). "Acoustic comfort as a salutogenic resource in learning environments—A proposal for the design of a system to improve the acoustic quality of classrooms," Sustainability **12**, 9733.
Li, H., and Lau, S.-K. (**2020**). "A review of audio-visual interaction on soundscape assessment in urban built environments," Appl. Acoust. **166**, 107372.
Luo, J., Wang, M., Chen, B., and Sun, M. (**2022**). "Exposure to nature sounds through a mobile application in daily life: Effects on learning performance among university students," Int. J. Environ. Res. Public Health **19**, 14583.
Ma, H., Su, H., and Cui, J. (**2022**). "Characterization of soundscape perception of preschool children," Build. Environ. **214**, 108921.
Massonnié, J., Frasseto, P., Mareschal, D., and Kirkham, N. Z. (**2022a**). "Learning in noisy classrooms: Children's reports of annoyance and distraction from noise are associated with individual differences in mind-wandering and switching skills," Environ. Behav. **54**, 58–88.

Massonnié, J., Frasseto, P., Ng-Knight, T., Gilligan-Lee, K., Kirkham, N., and Mareschal, D. (**2022b**). "Children's effortful control skills, but not their prosocial skills, relate to their reactions to classroom noise," Int. J. Environ. Res. Public Health **19**, 8815.

McAllister, A., Rantala, L., and Jónsdóttir, V. I. (**2019**). "The others are too loud! Children's experiences and thoughts related to voice, noise, and communication in Nordic preschools," Front. Psychol. **10**, 1954.

McKellin, W. H., Shahin, K., Hodgson, M., Jamieson, J., and Pichora-Fuller, M. K. (**2011**). "Noisy zones of proximal development: Conversation in noisy classrooms," J. Socioling. **15**, 65–93.

McManis, M. H., Bradley, M. M., Berg, W. K., Cuthbert, B. N., and Lang, P. J. (**2001**). "Emotional reactions in children: Verbal, physiological, and behavioral responses to affective pictures," Psychophysiology **38**, 222–231.

Mealings, K. (**2016**). "Classroom acoustic conditions: Understanding what is suitable through a review of national and international standards, recommendations, and live classroom measurements," in *Proceedings of Acoustics 2016: The Second Australasian Acoustical Societes Conference*, Brisbane, Australia, 9–11 November 2016, edited by I. D. M. Hillock and D.avid J. Mee.

Mitchell, A., Aletta, F., and Kang, J. (**2022**). "How to analyze and represent quantitative soundscape data," JASA Express Lett. **2**, 037201.

OECD (**2019**). "PISA 2018 Assessment and Analytical Framework" (OECD Publishing, Paris, France), available at https://www.oecd.org/pisa/publications/pisa-2018-results.htm.

Pellegatti, M., Torresin, S., Visentin, C., Babich, F., and Prodi, N. (**2023**). "Indoor soundscape, speech perception, and cognition in classrooms: A systematic review on the effects of ventilation-related sounds on students," Build. Environ. **236**, 110194.

Persson Waye, K., Van Kamp, I., and Dellve, L. (**2013**). "Validation of a questionnaire measuring preschool children's reactions to and coping with noise in a repeated measurement design," BMJ Open **3**, e002408.

Posner, J., Russell, J. A., and Peterson, B. S. (**2005**). "The circumplex model of affect: An integrative approach to affective neuroscience, cognitive development, and psychopathology," Develop. Psychopathol. **17**, 715–734.

Prodi, N., and Visentin, C. (**2015**). "Listening efficiency during lessons under various types of noise," J. Acoust. Soc. Am. **138**, 2438–2448.

Prodi, N., and Visentin, C. (**2022**). "A slight increase in reverberation time in the classroom affects performance and behavioral listening effort," Ear Hear. **43**, 460–476.

Prodi, N., Visentin, C., Borella, E., Mammarella, I. C., and Di Domenico, A. (**2021**). "Using speech comprehension to qualify communication in classrooms: Influence of listening condition, task complexity and students' age and linguistic abilities," Appl. Acoust. **182**, 108239.

Ratcliffe, E. (**2021**). "Sound and soundscape in restorative natural environments: A narrative literature review," Front. Psychol. **12**, 570563.

R Core Team (**2023**). *R: A Language and Environment for Statistical Computing* (R Foundation for Statistical Computing, Vienna, Austria), https://www.r-project.org/ (Last viewed March 31, 2023).

Riedel, N., Van Kamp, I., Dreger, S., Bolte, G., Andringa, T., Payne, S. R., Schreckenberg, D., Fenech, B., Lavia, L., Notley, H., Guski, R., Simon, D., Köckler, H., Bartels, S., Weber, M., and Paviotti, P. (**2021**). "Considering 'non-acoustic factors' as social and environmental determinants of health equity and environmental justice. Reflections on research and fields of action towards a vision for environmental noise policies," Transp. Res. Interdiscip. Perspect. **11**, 100445.

Schweiker, M., Ampatzi, E., Andargie, M. S., Andersen, R. K., Azar, E., Barthelmes, V. M., Berger, C., Bourikas, L., Carlucci, S., Chinazzo, G., Edappilly, L. P., Favero, M., Gauthier, S., Jamrozik, A., Kane, M., Mahdavi, A., Piselli, C., Pisello, A. L., Roetzel, A., Rysanek, A., and Zhang, S. (**2020**). "Review of multi-domain approaches to indoor environmental perception and behaviour," Build. Environ. **176**, 106804.

Senese, V. P., Ruotolo, F., Ruggiero, G., and Iachini, T. (**2012**). "The Italian version of the Weinstein Noise Sensitivity Scale: Measurement invariance across age, sex, and context," Eur. J. Psychol. Assess. **28**, 118–124.

Shu, S., and Ma, H. (**2019**). "Restorative effects of classroom soundscapes on children's cognitive performance," Int. J. Environ. Res. Public Health **16**, 293.

Stansfeld, S., Haines, M., and Brown, B. (**2000**). "Noise and health in the urban environment," Rev. Environ. Health **15**, 43–82.

Thompson, R., Smith, R. B., Bou Karim, Y., Shen, C., Drummond, K., Teng, C., and Toledano, M. B. (**2022**). "Noise pollution and human cognition: An updated systematic review and meta-analysis of recent evidence," Environ. Int. **158**, 106905.

Thompson, W. F., Schellenberg, E. G., and Husain, G. (**2001**). "Arousal, mood, and the Mozart effect," Psychol. Sci. **12**, 248–251.

Torresin, S., Albatici, R., Aletta, F., Babich, F., and Kang, J. (**2019a**). "Assessment methods and factors determining positive indoor soundscapes in residential buildings: A systematic review," Sustainability **11**, 5290.

Torresin, S., Albatici, R., Aletta, F., Babich, F., Oberman, T., and Kang, J. (**2019b**). "Acoustic design criteria in naturally ventilated residential buildings: New research perspectives by applying the indoor soundscape approach," Appl. Sci. **9**, 5401.

Torresin, S., Albatici, R., Aletta, F., Babich, F., Oberman, T., Siboni, S., and Kang, J. (**2020a**). "Indoor soundscape assessment: A principal components model of acoustic perception in residential buildings," Build. Environ. **182**, 107152.

Torresin, S., Aletta, F., Babich, F., Bourdeau, E., Harvie-Clark, J., Kang, J., Lavia, L., Raddichi, A., and Albatici, R. (**2020b**). "Acoustics for supportive and healthy buildings: Emerging themes on indoor soundscape research," Sustainability **12**, 6054.

Torresin, S., Albatici, R., Aletta, F., Babich, F., Oberman, T., Stawinoga, A. E., and Kang, J. (**2021**). "Indoor soundscapes at home during the COVID-19 lockdown in London – Part I: Associations between the perception of the acoustic environment, occupants' activity and well-being," Appl. Acoust. **183**, 108305.

Torresin, S., Albatici, R., Aletta, F., Babich, F., Oberman, T., Stawinoga, A. E., and Kang, J. (**2022a**). "Indoor soundscapes at home during the COVID-19 lockdown in London – Part II: A structural equation model for comfort, content, and well-being," Appl. Acoust. **185**, 108379.

Torresin, S., Ratcliffe, E., Aletta, F., Albatici, R., Babich, F., Oberman, T., and Kang, J. (**2022b**). "The actual and ideal indoor soundscape for work, relaxation, physical and sexual activity at home: A case study during the COVID-19 lockdown in London," Front. Psychol. **13**, 1038303.

Torresin, S., Aletta, F., Oberman, T., Vinciotti, V., Albatici, R., and Kang, J. (**2023**). "Measuring, representing and analysing indoor soundscapes: A data collection campaign in residential buildings with natural and mechanical ventilation in England," Build. Env. **243**, 110726.

Tsaligopoulos, A., Kyvelou, S., Votsi, N.-E., Karapostoli, A., Economou, C., and Matsinos, Y. G. (**2021**). "Revisiting the concept of quietness in the urban environment—Towards ecosystems' health and human well-being," Int. J. Environ. Res. Public Health **18**, 3151.

Ueno, K., Noguchi, S., and Takahashi, H. (**2019**). "A field study on the acoustic environment of special-needs education classrooms," Build. Acoust. **26**, 263–274.

Ulrich, R. S., Simons, R. F., Losito, B. D., Fiorito, E., Miles, M. A., and Zelson, M. (**1991**). "Stress recovery during exposure to natural and urban environments," J. Environ. Psychol. **11**, 201–230.

UNI 11532-2:2020 (**2020**). "*Caratteristiche Acustiche Interne di Ambienti confinati - Metodi di Progettazione e Tecniche di valutazione - Parte 2: Settore Scolastico*" (*Acoustics – Acoustical Characteristics of Indoor Environments – Design and Measurement Criteris – Part 2: Rooms for Learning*) (Ente Nazionale Italiano di Unificazione, Milano, Italy), http://store.uni.com/catalogo/uni-11532-2-2020 (Last viewed July 31, 2023).

Visentin, C., Pellegatti, M., Garraffa, M., Di Domenico, A., and Prodi, N. (**2023**). "Be quiet! Effects of competing speakers and individual characteristics on listening comprehension for primary school students," Int. J. Environ. Res. Public Health **20**, 4822.

Wang, M.-T., and Degol, J. L. (**2016**). "School climate: A review of the construct, measurement, and impact on student outcomes," Educ. Psychol. Rev. **28**, 315–352.

WHO (**2018**). *Environmental Noise Guidelines for the European Region* (World Health Organization, Regional Office for Europe, Copehagen, Denmark) (Last viewed July 31, 2023).

Xiao, J., and Aletta, F. (**2016**). "A soundscape approach to exploring design strategies for acoustic comfort in modern public libraries: A case study of the Library of Birmingham," Noise Mapp. **3**, 264–273.