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Noise monitoring in primary schools: comparisons between different time-dependent parameters for acoustic performance evaluation

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ABSTRACT

The A-weighted equivalent sound level is commonly used to describe or regulate environmental noise over a defined time interval. Although it is very convenient and easy to compare noise limits or requirements, it does not provide summary information on how noise evolves. On the other hand, the detailed analysis of the history of the measurements over time is too burdensome in the case of long-term monitoring. As part of a large study that aims to investigate the effects of noise on the cognitive abilities of primary school children, long-term unattended monitoring was carried out using low-cost instrumentation based on smartphone apps and calibrated external microphones. From the data obtained, acoustic indices and parameters were calculated, which allowed the assessment of the time-dependent noise exposure of the students based on the type of activity carried out in class. This analysis can be useful for validating the acoustic design requirements in schools.

1. INTRODUCTION

Providing optimal environmental conditions for occupants of indoor spaces has become increasingly crucial, especially in settings where acoustics can affect learning and listening abilities, such as in classrooms. Studies have shown that poor acoustic quality in school environments impairs students' performance and learning [1] and can also affect their future attainments [2]. As a result, many countries have adopted guidelines or regulations regarding the acoustic design of schools.

Schools' classrooms are commonly noisy environments because of external noise sources, such as traffic and play areas, and internal noise sources, such as the noise of moved chairs or desks, the children's talking, and the teaching activities carried out in the classroom.

The World Health Organization recommends a background noise limit of $L_{Aeq} \leq 35$ dB(A) and not more than 0.6 s for reverberation time [3]. Italian standard UNI 11532-2 [4] also defines the reference values of descriptors for representing the acoustic quality of classrooms.

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Different types of measurements are available to assess noise pollution, such as the equivalent sound level (L_{eq}) and the equivalent sound level measured over 8 hours ($L_{ex,8h}$). The equivalent level L_{eq} allows quantifying the average sound intensity during a given time duration. It considers both exposure duration and sound intensity. $L_{ex,8h}$ is a measure of the average noise level to which a person is exposed during an 8-hour workday, considering the intensity and duration of noise exposure. However, these parameters do not identify the temporal dynamics of the noise a person is exposed to. In fact, it has been shown that students are more disturbed by intermittent noise than by constant noise [5].

This study aims to investigate to what extent continuous monitoring of classroom noise conditions allows for describing the temporal dynamics of noise that may occur during different teaching activities and whether this description is useful for characterizing soundscapes.

2. METHODS

2.1. Classrooms and schools

Long- and short-term acoustic monitoring was carried out in some fourth-grade classes (9-10 year-old children) of two primary schools in the province of Padova, Italy. From the point of view of the external soundscape, the two schools can be considered similar, located in residential areas with low traffic intensity. The structures are developed on the ground floor in the case of School A, while on one floor in the case of School B, they were built in the 1970s, and a large green area surrounds both. During the absence of school activities and under normal external traffic conditions, an L_{Aeq}<30 dB(A) was measured.

The classrooms have large windows on one wall (one classroom has windows on two sides) and still need to be refurbished or equipped with measures to improve indoor acoustics. In addition, there is no mechanical room ventilation system. The heating system is by radiators for School A and underfloor heating for School B.

The monitored classrooms in School A are arranged on the ground level, while those in School B are on the first level.

Six classrooms, four with full-time classes and two with half-time classes, were monitored (two in School A and four in School B, located in the two wings of the building on the first level). Details of the monitored classrooms are presented in Table 1.

Table 1: Main characteristics of monitored classes.

Scholastic year under analysis	School	Class	Volume	Pupils' number
2022-2023	A	A1	142 m^3	22
		A2	140 m^3	23
2023-2024	B	B1	129 m^3	16
		B2	148 m^3	18
		B3	138 m^3	17
		B4	132 m^3	20

2.2. Equipment and procedure

The surveys were carried out with an iPad for each monitored class equipped with the OpeNoise app [6]. An omnidirectional condenser microphone was connected to the iPad. The instrumental chain was calibrated at the reverberation room of the acoustics laboratory "LabAcus" of the Department of Industrial Engineering of the University of Padova by comparing it with a reference sound source [7].

For each day of monitoring, the instrumentation was placed and collected before the start of classes and after the end of classes. The teachers of the monitored classes were asked to fill in a calendar by entering, for each hour of class, the subject and teaching activity done thus divided:

- Oral teaching: The teacher is talking, and pupils are seated at their desks.
- Individual activity: Exam, writing, or drawing, pupils are seated at their desks with the teacher's supervision.
- Interactive education: Dialogue between the students and the teacher.
- Team activities: Several people speaking and moving, music.

Each monitored class was acoustically characterized by Reverberation Time (RT) and Speech Transmission Index (STI) measurements according to the indications in ISO 3382 [8] and UNI 11532-2 standards.

2.3. Measured parameters

The parameters that are calculated from L_{Aeq1s} of each class hour, acquired from the instrumental monitoring chain, are the "Intermittency Ratio" (IR) [9], which allows characterizing the variability of noise exposure taking into account the number and magnitude of noise events that occur, and the value of L_{A95} to determine the background noise. In particular, although the IR index was designed to characterize exposure to noise from transportation infrastructure, it has been observed that peaks of IR correspond to situations that are particularly severe or directly affect subjects [10]. Therefore, the use of IR could help identify situations in which the variability of L_{Aeq} is critical.

3. RESULTS

3.1. Acoustic measurements

By comparing RT and STI with the octave band reference values given in UNI 11532-2, it was identified that no classroom meets the national standard's requirements. See Table 2.

Table 2: Room acoustic conditions in classrooms of Schools A and B. RT is the mean reverberation time within 125-4000 Hz. STI is the mean in pupil’s area measured according to UNI 11532-2 standard.

School	Classroom	RT [s]	STI
A	A1	1.55	0.56
	A2	1.36	0.54
B	B1	1.62	0.50
	B2	1.42	0.54
	B3	1.78	0.49
	B4	1.36	0.56

3.2. Comparison between time-dependent parameters

Since the number of students present within each class in the two schools monitored was similar, the calculated values were collected into two groups based on the volume/student ratio. The first includes classes A1 and A2; the second contains classes from B1 to B4.

Figures 1 and 2 show boxplot diagrams of the calculated hourly IR index values by teaching activity during school hours, grouped for the two schools. It can be observed that, in both schools, oral teaching has a lower IR than that calculated in individual activity, while the IR of team activities has lower values.

Figures 3 and 4 report the minimum and maximum index IR calculated for each teaching activity in two schools and the minimum and maximum L_{A95} values.

It is clear that high values of the IR index result in lower L_{A95}. This is because, as there is less background noise, there is more intermittency.

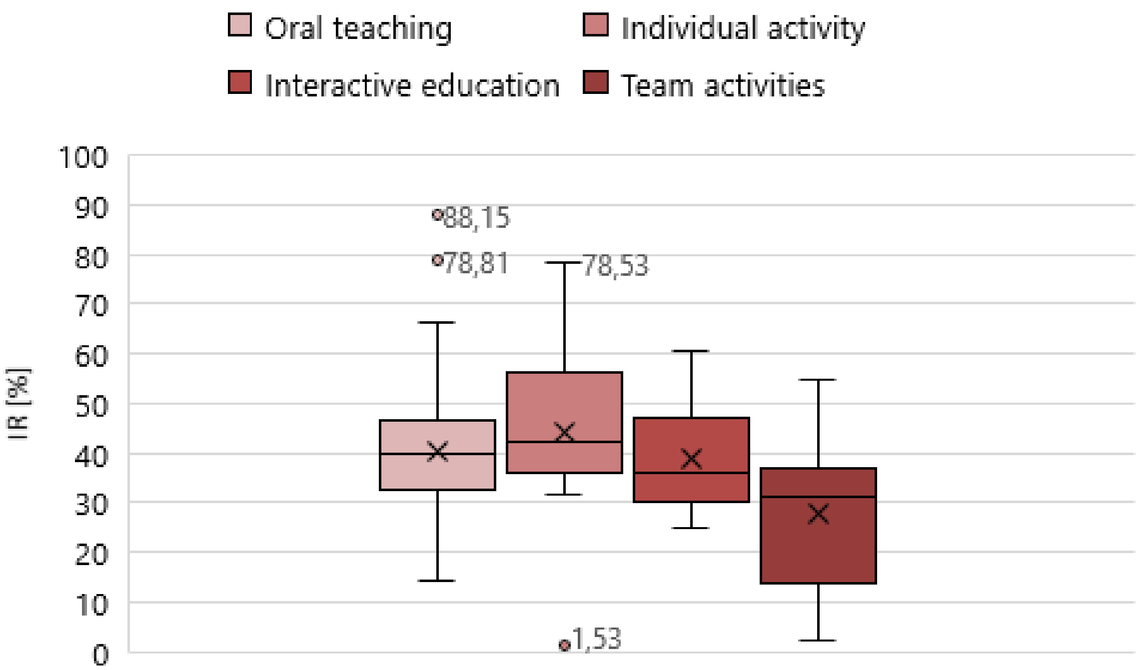

Figure 1: Boxplot of IR values by teaching activity in School A, classes A1 and A2.

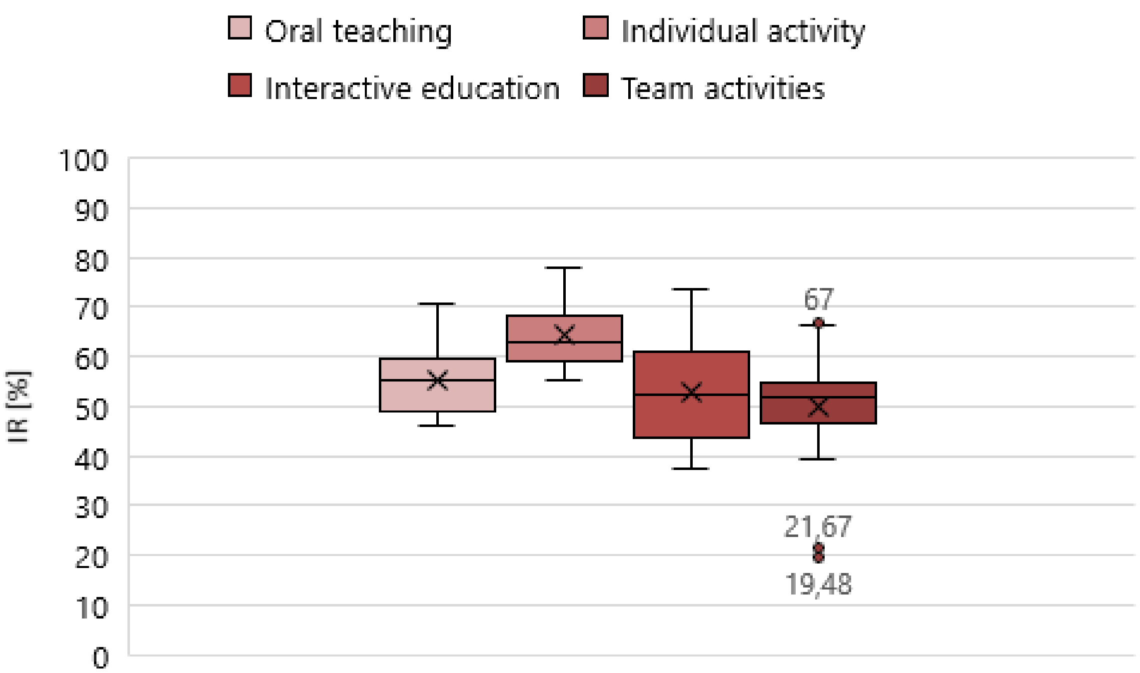

Figure 2: Boxplot of IR values by teaching activity in School B, classes B1-B4.

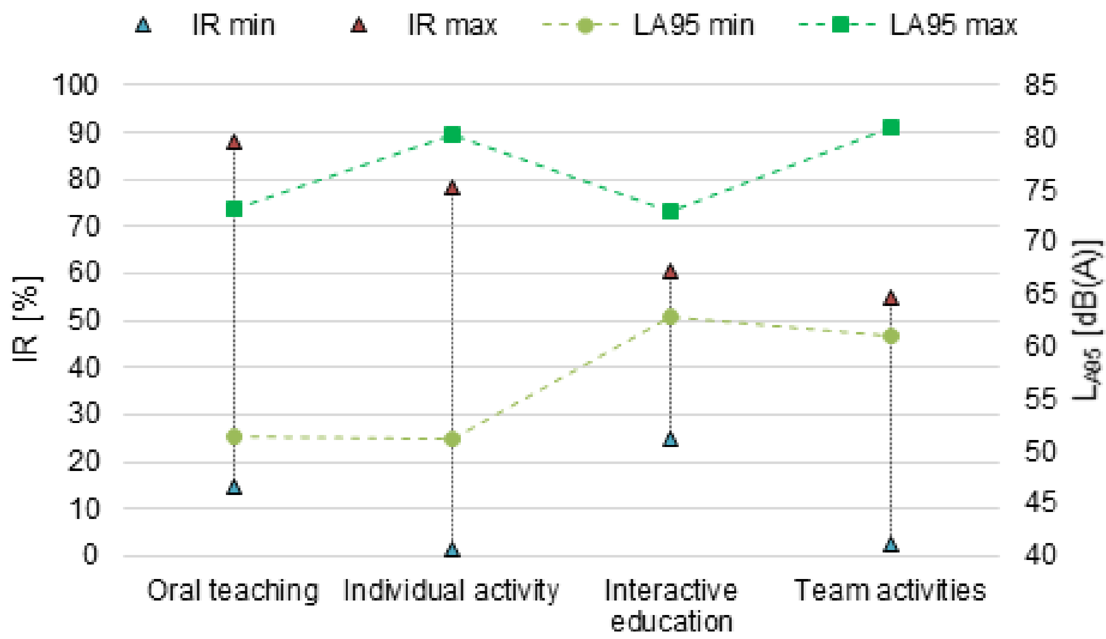

Figure 3: Min and max IR values and min and max L_{A95} values by teaching activity in School A, classes A1 and A2.

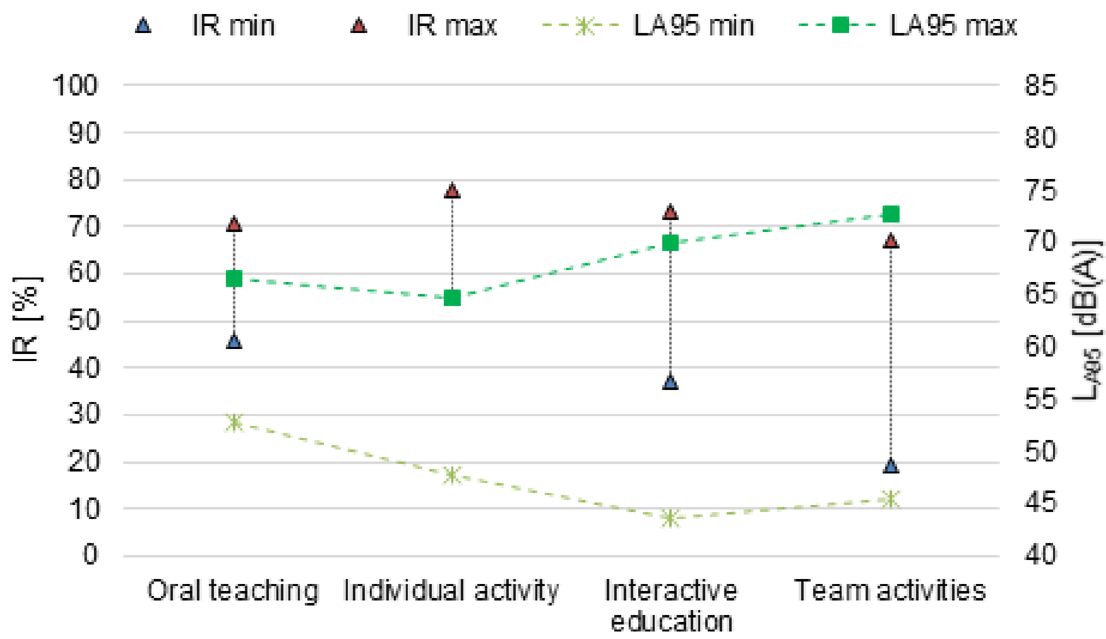

Figure 4: Min and max IR values and min and max L_{A95} values by teaching activity in School B, classes B1-B4.

Teaching activities are standardized: i.e. face-to-face lectures and activities are conducted in quiet, and it is possible to make a comparison between the IR index values obtained in the two schools. Calculating the difference between the median IR index of School B and the median obtained in School A, it is possible to see greater intermittency in School B. This is because there are far fewer children in classes B1-B4 than there are in classes A1 and A2. See Table 3.

Table 3: Difference between medians measured in frontal teaching and individual teaching (quiet condition) activities in Schools B and A.

	Oral teaching	**Individual activity**
∆IR median (School B − School A) [%]	15,2	21,1

4. DISCUSSION

The analysis of temporal noise dynamics parameters, conducted by monitoring data in primary school classrooms, offered interesting suggestions. The influence of the type of teaching adopted and the number of students in the classroom was highlighted. It was observed that a lower number of students results in a lower level of background noise and the presence of greater intermittency due to the non-masking of events that may occur. The same reasoning can also be applied to the type of teaching activity. In fact, in group teaching, the presence of more background noise due to greater movement by occupants or the presence of other sources of noise results in lower intermittency. This is not true in individual teaching activity, in which background noise levels are low, and therefore, the occurrence of events that are not masked results in increased intermittency.

It is important to highlight that in School B, teachers change the arrangement of desks in classrooms during different teaching activities. This is practicable due to the low number of pupils and the large size of the classrooms. Such practices are not adopted in School A classrooms due to the high number of children in the classroom. Consequently, despite the high reverberation time and STI values in the classrooms of the two schools, appropriate space and layout management can compensate for the architectural acoustic deficits in the classrooms.

The exclusive use of L_{Aeq} for noise description proves to be insufficient, especially considering the potential disturbance effects. Therefore, a need to consider additional parameters to describe the temporal dynamics of sound levels resulting from children's activities emerges. This study proposes a new approach to assessing the acoustic performance of school environments, which are subject to varying noise levels depending on the context and the number of people present. This approach makes use of indices that allow for a more complete and accurate analysis of the temporal dynamics of noise.

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