Assessment of indoor ambient noise level in school classrooms

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Summary
Previous studies have shown that poor acoustic conditions inside classrooms interfere with an optimal teaching-learning process. Since high background noise levels and long reverberation times cause higher vocal use among teachers, and lower understanding among students, it is recommended to guarantee physical conditions inside the classrooms that ensure optimal conditions for teaching and learning. To reach this goal, it is important to characterize and control two main factors, namely reverberation and noise. This work focuses on measurement and analysis procedures of indoor ambient noise level during primary school classroom activities, with the main objective to optimize the measurement procedure (data acquisition and elaboration) of background noise in real environments. The presented noise levels were measured in three classrooms in a primary school in Torino (before and after acoustical treatment). They were monitored for the entire duration of classroom activities by positioning a sound level meter near to the teacher's desk, at least one meter far from every surface. From every long-term measurements (LTMs), short-term measurements (STMs) of one, five and 15 minutes were extracted randomly. LTMs and STMs were elaborated in terms of A-weighted equivalent sound pressure level (L_{Aeq}) and of A-weighted statistical sound pressure level (L_{A90} that corresponds to the level which is overtaken for the 90% of the measurement duration). After every monitored activity teachers filled in a questionnaire on work-related conditions. Associations between self-reports and objective LTMs and STMs of noise during teaching hours were determined using Generalized Estimating Equations (GEEs).

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1. Introduction

In order to guarantee a proper physical environment for education, acoustic conditions that contribute to improve communication process inside the classrooms are required. Learning activities interest the majority of the first years of a person's life, both from a student's and from a teacher's point of view. Adequate acoustic conditions are therefore needed in classrooms to increase speech intelligibility and to reduce teachers' vocal load [1-3]. A main issue that has already been explored in previous studies [4-6] is that excessive reverberation and indoor ambient noise may contribute to worsen academic results. Detrimental effects especially regard young children and people with hearing-, language- or learning-impairments. Acoustic discomfort for both teachers and pupils, due to both reverberation and noise, may generate headache, nervousness or decreasing in concentration, which influence the way an activity is performed (teaching and learning). Reverberation effects can be controlled throughout construction or renovation processes, so that conformance to the requirements of existing standards or guidelines is guaranteed [7-11]. Noise influence is instead mainly related to external sources (e.g. traffic noise, playgrounds), acoustic performances of the building envelope and partitions, and to indoor sources which might be of human nature (e.g. chatting, walking, sliding of chairs or tables) or due to heating, ventilating, and air-conditioning (HVAC) systems. Improving acoustic conditions inside the classrooms and schools is therefore a matter related to the building and systems design, but also to the human behavior management. When evaluating indoor ambient noise inside classrooms, attention should be paid to several aspects, such as:

- duration of the measurement (e.g. adjustment of results if measurements are carried out for durations that are shorter than the reference time interval of 5-10 minutes to account for traffic flows, weather conditions, etc. [7]);
- characteristics and position of the microphone(s) in the room [7];
- data analysis using spectral or single number descriptions [7,8,12].

Practical experiences show that in-field noise measurements are time demanding, difficult to elaborate due to big amounts of data, and require accurate instruments to be reliable. Some main issues relate to the use of a representative parameter to describe indoor environmental noise, and to the advisable time-length for an accurate measurement. The BB93 reference [8] suggests to assume as indoor ambient noise the equivalent continuous A-weighted pressure level measured for a time interval of 30 minutes in unoccupied classroom condition. This equivalent continuous level does not account for possible changes due to real teaching situations where indoor noise variations lead to other consequences, such as an increase in the voice level of teachers. Recent studies have therefore began studying the relation between noise level, type of lesson, subjective impression and voice use [3,13]. This paper has the main aim to investigate on procedures that allow optimizing data acquisition and elaboration of indoor ambient noise levels. Several long-term measurements (LTMs) were performed in three classrooms of a primary school in Torino (Italy), before and after an acoustical treatment. Noise was analyzed as A-weighted equivalent sound pressure level (L_{Aeq}) and A-weighted percentile sound pressure level (L_{A90}). Short-term measurements (STMs) considering different time-intervals were then randomly extracted from the LTMs to investigate their accuracy in estimating L_{Aeq} and L_{A90}. After every monitoring, teachers were asked to rate the degree of annoyance due to the noise condition they were exposed to during the teaching activity. In particular, teachers had to put a cross on a 10 cm line to identify the degree of perceived noise level in the classroom compared to the condition of empty room and empty school at the beginning of the day, having “very low” and “very high” as extreme ratings. This subjective impression was related to the objective measure of noise in classrooms to investigate on possible associations and is also described in the paper.

2. Methods

2.1. Case studies

Noise monitorings took place in a primary school located in the center of Torino, nearby low traffic arteries. The school building dated back to late XIX century and presented high ceilings classrooms with vaults (height of 4.9 m, volume ≈ 240 m^3). The noise condition to which four teachers were exposed was monitored in three rooms with inadequate acoustics. After a low-cost and light project to enhance the acoustical quality, noise was monitored again in the same classrooms. Rooms acoustic characterization is given in [14]. Table 1 shows the main acoustic parameters in the three rooms, before and after the acoustic renovation.

Table 1. Parameters before and after the acoustical treatment, in occupied (occ.) and unoccupied (unocc.) classrooms. Standard deviations are reported in brackets for frequency averaging and repeated measurements. STIPA refers to two voice sound pressure levels and background noise levels. Optimal values are reported in brackets in the *condition* column.

	Condition	*Before*	*After*
$T_{30,0.5\text{-}1kHz}$ (s)	unocc.(0.8)	2.4 (0.04)	0.9 (0.04)
	occ.(0.6)	1.3 (0.04)	0.6 (0.03)
$C_{50,0.5\text{-}1kHz}$ (dB)	unocc.(-)	-3.2 (0.3)	2.9 (0.2)
	occ.(≥0)	-3.8 (0.3)	4.9 (0.2)
STIPA (-)	occ.(≥0.6)	0.57 (0.02)	0.71 (0.14)

2.2. Data acquisition

The teaching conditions of four teachers was monitored for several days measuring noise levels during work hours. A sound level meter (two chains were used in the monitorings, namely XL2 by NTi Audio and type 2222 by Bruel&Kjaer with a H1 by ZOOM as data logger) was placed at 1.5 m from the ground, at least 1 m far from each reflective surface but close to the desk where the teachers used to stay, in compliance with ISO 1996 recommendations [7]. Indoor ambient noise was acquired continuously for the entire duration of each lesson. Data analysis was performed with the aim of Matlab®. As suggested in [7,8], noise level was evaluated in terms of L_{Aeq}, therefore taking into account the overall noise level due to all activities (e.g. teaching, studying, playing, moving). The percentile level L_{A90} was afterwards evaluated to establish to which noise condition teachers were exposed because of background sources such as HVAC systems, outdoor traffic, playground activities.

2.3. Statistical analysis

Statistical analyses were performed with SPSS software (version 21; SPSS Inc, New York, NY). Descriptive statistics was used to characterize the indoor ambient noise levels inside classrooms. Since STMs where more than one within each length (one, five and 15 minutes) of LTMs, analyses were performed using the average values of all the STMs. The Shapiro-Wilk test [15] was used to evaluate whether variables were normally distributed (data not shown). The normalized error concept [16] was applied to assess compatibility between LTMs and STMs. Then, the simple linear regression analysis was used to investigate associations between LTMs with the STMs and the self-reports of noise conditions.

3. Results

3.1. Differences between long- and short-term measurements of indoor ambient noise

Complete averaged results for LTMs of 3 to 4 hours and STMs are reported in the Appendix in Table 4. Mean values across monitorings are reported below. In total, 14 LTMs were analyzed, and 77, 77 and 75 STMs were extracted for one, five and 15 minutes intervals, respectively.

3.1.1. $L_{A,eq}$ (activity noise)

Mean L_{Aeq} during the LTMs was 77.2 dB(A) with standard deviation (SD) of 3.3 dB(A). Mean L_{Aeq} of the STMs of 15 minutes was 74.9 dB(A) with a SD of 5.2 dB(A). Mean L_{Aeq} of the STMs of five minutes was 74.5 dB(A) with a SD of 6.1 dB(A). Mean L_{Aeq} of the STMs of one minute was 72.9 dB(A) with a SD of 7.4 dB(A). Table 1 shows that the mean difference between the LTMs and the STMs decreases when STMs' length increases, indicating, as expected, that the STMs of 15 minutes produce more similar results to the LTMs compared with the STMs of one and five minutes.

Table 2. Mean difference of L_{Aeq} between long- and short-term measurements (LTM and STM, respectively). Differences are reported for measurements taken in classrooms before (bef. a.t.) and after (aft. a.t.) the acoustical treatment too.

Difference on L_{Aeq}	*All data [dB]*	*Bef. a.t. [dB]*	*Aft. a.t. [dB]*
LTM - STM (1 min)	4.4	3.2	7.1
LTM - STM (5 min)	2.9	2.4	3.8
LTM - STM (15 min)	2.4	2.0	3.4

3.1.2. L_{A90} (background noise)

Mean L_{A90} during the LTMs was 56.9 dB(A) with a standard deviation (SD) of 5.8 dB(A). Mean L_{A90} of the STMs of 15 minutes was 59.7 dB(A) with a SD of 7.4 dB(A). Mean L_{A90} of the STMs of five minutes was 61.2 dB(A) with a SD of 8.3 dB(A). Mean L_{A90} of the STMs of one minute was 62.5 dB(A) with a SD of 9.1 dB(A). Table 2 shows that the mean difference between the LTMs and the STMs also decreases when the length of the STMs increases, indicating that the STMs of 15 minutes produce more similar results to the LTMs compared with one and five minutes STMs.

Table 3. Mean difference of L_{A90} between long- and short-term measurements (LTM and STM, respectively). Differences are reported for measurements taken in classrooms before (bef. a.t.) and after (aft. a.t.) the acoustical treatment too.

Difference on L_{A90}	*All data [dB]*	*Bef. a.t. [dB]*	*Aft. a.t. [dB]*
LTM - STM (1 min)	-5.9	-6.5	-4.5
LTM - STM (5 min)	-4.6	-4.7	-4.5
LTM - STM (15 min)	-3.1	-2.9	-3.4

3.1.3. Normalized error concept implementation and association analysis

The normalized error (E_N) can be used to compare measures at the same hierarchical level. It is the ratio between the absolute value of the difference of two states and the expanded uncertainty of the difference, as shown below (1):

$$E_N = \frac{|x_1 - x_2|}{k \cdot \sqrt{s(x_1)^2 + s(x_2)^2}} \quad (1)$$

where x_1 and x_2 are the values of the two states, which are considered as statistically independent, $s(x_1)$ and $s(x_2)$ are their experimental standard deviations, and k is the coverage factor. In the present discussion k is assumed as equal to 2, which is significant at 95% confidence interval.

If E_N value is higher than one, the difference between the two states is not merely due to random effects and the two results can be considered incompatible. If E_N is lower than one, the difference can be due to random effects which may cover real differences or systematic effects, so there is no reason to refuse compatibility.
The normalized error concept was applied in this work to investigate on the compatibility between LTMs and STMs (results in Table 4). All outcomes resulted to be below one, except the case of comparison between LTM and one minute STM in the case of L_{Aeq} in acoustically treated classrooms. This incompatibility might be due to the high variability of activity noise during lessons and to the small number of averaged measurements, in comparison with the other conditions (all classrooms and classrooms before acoustical treatment).

Table 4. Normalized Error (E_N) of the difference between L_{Aeq} and L_{A90} obtained for short-term monitorings (1, 5 and 15 minutes) compared to long-term acquisitions. Values in bold refer to incompatible measures.

STM duration	*Condition*	*Parameter*	
		L_{Aeq}	L_{A90}
$E_{N,LTM\text{-}1min}$	all classrooms	0.6	0.5
	before a.t.	0.4	0.5
	after a.t.	**1.2**	0.7
$E_{N,LTM\text{-}5min}$	all classrooms	0.4	0.3
	before a.t.	0.3	0.4
	after a.t.	0.7	0.6
$E_{N,LTM\text{-}15min}$	all classrooms	0.3	0.2
	before a.t.	0.3	0.3
	after a.t.	0.5	0.5

3.2. Relation between self-report of noise conditions and indoor ambient noise measurements

The linear regression analysis suggests a significant association between LTMs and STMs for L_{Aeq} and L_{A90} characterization inside occupied classrooms. Considering all the monitorings together, a higher correlation between LTM and STM was found for L_{A90} in the case of STM of 15 minutes (regression coefficient = 0.98, *p-value* < 0.05) compared with the STM of one minute (regression coefficient = 0.66, *p-value* < 0.05). The same tendency is observed in L_{Aeq} with a higher correlation in the STM of 15 minutes (regression coefficient = 0.91, *p-value* < 0.05) compared with the STM of one minute (regression coefficient = 0.56, *p-value* < 0.05). When considering stratified monitorings (divided per classroom acoustic conditions), the regression analysis shows that before the acoustical treatment LTM is significantly associated (*p-value* < 0.05) with the three lengths of STM (in both L_{A90} and L_{Aeq}). The associations are not present after the acoustical treatment, but this can be due to the small sample size of the monitorings performed in classrooms with adequate acoustic conditions.
To assess association between objective measurements and subjective impression on noise condition via self-reports data were analyzed through a linear regression. No linear association was found for L_{Aeq} either L_{A90} between measured and self-reported noise conditions, for any long-term and short-term monitoring duration.

4. Conclusions

This work is a primary attempt in finding an easy, repeatable and accurate procedure for noise monitoring in teaching and learning environments. The activity of four teachers in three classrooms was monitored before and after the acoustical treatment of rooms. Long-term noise monitorings (LTMs) were acquired for the entire duration of the observed lessons. Short-term monitorings (STMs) were then randomly extracted with different time-lengths (one, five and 15 minutes) to investigate their accuracy in estimating noise condition (equivalent and percentile A-weighted sound pressure levels) with respect to the entire lessons' monitorings. Applying the normalized error concept (E_N) to LTMs vs STMs, the comparison for all classroom conditions (before and after acoustic treatment) and all time intervals shown a value lower than one, giving compatibility between all STMs and LTMs. A tendency of lowering in the E_N was found when the monitoring length increased, as expected. The obtained results therefore suggest that measurement of the activity noise (L_{Aeq}) and of the background noise (L_{A90}) inside occupied classrooms for intervals of 15 minutes produce similar results to the values obtained during a LTM. In particular, classrooms with higher reverberation times had smaller differences between LTM and 15 minutes STM (2.4 dB of difference as an average for all classrooms, 2.0 dB and 3.4 dB of difference in the case of classrooms before and after the acoustical treatment, respectively). When a measurement of 15 minutes is not possible, a measurement of at least five minutes is advisable to account for weather, traffic and other noise sources variations in the propagation path, but then a time-length increase can be necessary get a representative sample of source operating conditions [7]. This result is also in agreement with the linear regression analysis, which shows a significant association between LTMs and every length of the STMs.

The relation assessment between self-reported noise annoyance and measured noise level during teaching activities show no association, which may depend on the combined effect of several factors on which further research is needed, such as clustering measurements on the base of the type of lesson (plenary, shared, group, watching/listening, etc.) or on the type of taught subject.

Appendix

Table 4. Results for long-term measurements (LTMs) and short-term measurements (STMs) at different time lengths. Results refer to A-weighted equivalent (L_{Aeq}) and percentile (L_{A90}) sound pressure levels (NA=not available).

n	*Entire monitoring (N=14)*		*1 minute (N=77)*		*5 minutes (N=77)*		*15 minutes (N=75)*	
	L_{Aeq}	L_{A90}	L_{Aeq}	L_{A90}	L_{Aeq}	L_{A90}	L_{Aeq}	L_{A90}
1 (n=5)	70.4	56.0	67.8 (4.5)	56.6 (5.0)	70.1 (2.0)	55.9 (1.4)	70.1 (1.0)	56.1 (1.1)
2 (n=6)	82.0	65.6	78.6 (6.5)	71.3 (9.2)	77.9 (2.5)	69.4 (4.7)	77.5 (3.2)	68.7 (4.7)
3 (n=6)	79.3	60.1	76.2 (5.6)	64.6 (8.0)	77.9 (4.7)	64.9 (5.1)	78.0 (3.7)	63.8 (6.0)
4 (n=6)	77.0	54.0	76.6 (5.8)	65.3 (11.1)	77.7 (4.5)	62.4 (10.6)	75.2 (5.3)	56.6 (10.5)
5 (n=5)	82.5	64.0	81.4 (5.0)	74.8 (4.8)	80.1 (6.2)	69.7 (8.8)	78.8 (4.5)	67.8 (6.5)
6 (n=3)	78.3	59.3	76.8 (0.5)	61.9 (4.0)	77.2 (0.8)	61.9 (5.4)	77.4 (4.1)	62.6 (4.3)
7 (n=6)	77.6	47.7	69.7 (12.6)	62.9 (11.7)	70.7 (11.5)	59.7 (12.3	74.0 (8.4)	57.9 (10.2)
8 (n=5)	78.6	64.7	75.5 (1.5)	70.3 (2.0)	76.9 (3.0)	68.4 (5.0)	77.9* (3.9)	66.2* (3.8)
9 (n=5)	77.1	56.5	73.6 (3.3)	60.2 (4.0)	73.3 (5.8)	56.7 (3.9)	76.1 (4.5)	57.8 (3.7)
10 (n=5)	78.1	60.7	74.2 (7.0)	62.1 (5.5)	75.9 (4.5)	63.2 (5.5)	77.7 (3.8)	60.0 (4.9)
11 (n=11)	77.7	52.6	70.2 (5.5)	59.5 (7.2)	73.2 (5.9)	60.1 (6.8)	71.4* (4.7)	57.3* (6.1)
12 (n=5)	75.6	53.8	69.0 (6.3)	54.9 (10.4)	72.6 (4.7)	57.2 (8.6)	75.3 (4.2)	56.5 (5.8)
13 (n=4)	73.0	48.2	69.9 (7.5)	55.7 (5.8)	69.6 (2.0)	52.0 (3.1)	70.6 (3.7)	50.8 (4.2)
14 (n=5)	73.1	53.0	63.1 (5.4)	53.5 (3.2)	69.5 (6.4)	52.5 (3.5)	72.0 (5.4)	55.2 (2.1)

* Given as *n* the number of STMs across each LTM, these mean values correspond to *n*-1 averaged STMs.

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