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A pilot study in primary school on the effect of noise monitoring system with lighting feedback on teachers' voice parameter, noise levels and subjective assessments

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ABSTRACT

Teachers' vocal behaviour is affected, among other aspects, by the noise generated by pupils that talk and move in classroom. Under noisy conditions, teachers are likely to increase their voice level causing possible negative consequences on their vocal health. In this pilot study a noise monitoring system with a lighting feedback, namely the SEM (Speech and Sound SEMaphore) device, has been used as an educational tool. It encourages pupils to reduce their voice volumes through a coloured lighting feedback. Seven teachers from four classes of a primary school in Turin (Italy) have been monitored over two to four working days with SEM switched on and off. The results have shown that the background noise level averagely decreased by about 2.9 dBA when SEM was switched on. With SEM switched off, a tendency towards Lombard effect has occurred, i.e. an increase in the speech level with background noise level at a rate of about 0.4 dB/dB. Conversely, such effect has not been found with SEM switched on. Self-reported impressions of teachers indicated that SEM effectively reduces vocal effort and improves speech intelligibility in the classroom.

Keywords: Vocal load, Noise, Classrooms

1. INTRODUCTION

Classroom acoustics may generate challenging environments for both students and teachers, as it influences speech intelligibility and the required vocal effort in order to be understood, respectively. Particularly, when poor acoustics is present it may degrade the students' performance [1] and bring teachers to excessively raise voice with possible negative consequences on their vocal apparatus [2].

Together with the objective assessment of a classrooms' quality and students'/teachers' performances in it, there is an increasing observation of the subjective perception of the acoustic environment by means of questionnaires. Particularly, questions on the perceived noise annoyance and on the most heard sound source in classrooms have brought to light that students' activity is perceived as the main source of noise in classrooms within the combination of different sounds. In a subjective investigation on 51 classes, Astolfi et al. [3] found that student conversations and movements were perceived as the highest noisy source in terms of intensity, frequency and disturbance in primary school classrooms. The accurate monitoring of classroom noise during the teaching activity is therefore fundamental, especially to evaluate the relationship between self-perceived annoyance and objectively measured noise. As an example, Sato and Bradley [4] quantified that an average increase in background noise levels by about 10 dBA was generated by students during teaching activities.

In this framework, it is still unknown whether the involvement of occupants' behaviour could generate some effects on background noise levels and teachers' voice status. An innovative method based on a visual system with coloured lighting feedback has been applied to control noise levels through the visualization of sound conditions encouraging lower students' voice volume when noise

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levels are elevated, however still on a small scale. Prakash et al. [5] pointed out that teachers, students and management area (i.e. secretary deputy head teacher or head teacher) self-estimated the usefulness of such a visual feedback system in school. The use of the SoundEar II device [6], led to improve the teaching process and classroom environment, as well as to reduce background noise levels in three classes involved in a short-term experiment [7]. Nonetheless, in order to increase the knowledge about the effects of occupants' behavior on learning and teaching process, research on the use of visual feedback system as an educational tool is still required to provide evidence of its benefits in terms of noise reduction and vocal effort. Such aspect of voice use in relation with activity noise, in fact, still needs to be deepened with in-field, prolonged and repeated measurement campaigns that make use of accurate tools too.

For this purpose, a pilot study was performed using a noise monitoring system with the lighting feedback during long-terms voice monitoring in four primary school classrooms. The aim of this pilot was to evaluate the extent to which the presence of a noise monitoring system could encourage teachers to reduce their vocal effort during plenary lessons due to a greater awareness of noise conditions, and to reduce the background noise levels generated by positive pupils' behaviour.

2. METHODOLOGY

2.1 Case studies

The present pilot study involved four classrooms belonging to a primary school placed in a residential area of the center of Turin (Italy) that dates back to the nineteenth century. Due to their location in the school building, classrooms either faced a road with low traffic or the internal courtyard, therefore external noise is not a predominant source of disturbance. Geometry and finishes in the classrooms are very similar; they all present large windows, earthenware tiles on the floors, high vaulted ceilings and acoustically treated walls, the latter consisting of plasterboard tiles (1.2 x 2.4 m, with a percentage of perforation of 16%) with an air gap of 7.5 cm from the walls. The BS EN ISO 3382-1 standard [12], using the integrated impulse response method, was applied for measurements of reverberation time (T_{30}) in the school classrooms, which had the average volume of 240 m^3. The mean reverberation time was 0.9 s in unoccupied condition and 0.6 s in occupied condition in the mid-frequency range (from 0.5 kHz to 1 kHz). The acoustical renovation and measurements are described in detail in Astolfi et al. [8].

2.2 Monitoring of background noise levels

2.2.1 Device and procedure

A noise monitoring system with the lighting feedback, namely SEM (Speech and Sound SEMaphore), was used to measure and control background noise levels during teaching activities in primary school classrooms based on an adjustment of pupils' behaviors, such as lowering voice volumes. The SEM device has been developed, validated and patented at Politecnico di Torino.

The SEM device, which detailed description is given in Di Blasio et al. [9], consists in a class 2 sound level meter device (ISO-TECH SLM 52N) that measures background noise levels (L_{A90}), and in a transparent panel illuminated by a through-light beam. The lighting feedback alternates colours from green, yellow and red according to the change of background noise levels.

The long-term noise monitoring was performed across three school years in three successive campaigns using SEM devices located close to whiteboard and teachers' desk in front of pupils in a total of thirteen classes (four to five per year). The present work reports the methods and results related to the third monitoring campaign in which, in addition to the use of the SEM device as an educational tool, the teachers' vocal activity and subjective assessments were evaluated. Overall, the monitoring campaign was divided in phases according to lighting feedback of the SEM device, as follows: phase one (P1), with SEM switched off and pupils unaware of the ongoing monitoring in order to be not influenced by an a-priori information; phase two (P2), with SEM switched on and pupils aware of the ongoing monitoring, as they were informed of the relationship between the colours of the warning light and the noise levels produced by themselves.

The background noise levels were recorded in both phases using the SEM device itself. Teachers were asked to switch off and on SEM device and to note different variables in a daily logbook, e.g. type of activity and the respective time-slot, own name, number of pupils, day of the week and possible noise events coming from outside.

2.3 Monitoring of teachers' vocal activity

2.3.1 Subjects

One male and six female teachers have been monitored from two to four working days (3-4 hours per each monitoring) over two different time periods according to P1 and P2 of the noise monitoring campaign. Both phases of the long-term voice monitoring were carried out in the middle of the school year with a distance from each other of four to six weeks. Teachers' age ranged between 38 and 60 years, with a mean age of 48. Voice monitoring campaign involved four classes from first to fourth grade (with pupils' age from 5 to 9 years), where the number of pupils varied between 12 and 25 depending on the day and class. Table 1 shows the characteristics of the subjects and the total number of long-term voice monitoring performed for each teacher according to the two monitoring phases.

Table 1 – Main characteristics of the classes and the teachers, and the total number of long-term voice monitoring for each one, subdivided according to P1 and P2.

Classes		Teachers			Number of voice monitoring	
Grade	Pupils' number	ID	Age	Gender	P1	P2
I A	20-22	a	47	M	1	1
		b	41	F	2	0
II B	12-14	c	38	F	1	1
		d	55	F	2	2
II C	17-19	e	50	F	1	2
IV D	23-25	f	47	F	2	2
		g	60	F	1	1

2.3.2 Recording equipment and procedure

The long-term voice monitoring was carried out using a portable vocal analyzer, based on Voice Care technology, that has been developed at the Politecnico di Torino by Carullo et al. [10-12]. This device consists of a Piezoelectric Contact Microphone (HX-505-1-1, Shenzhen, China), embedded in a collar, that has been placed near the jugular notch to sense the acceleration of the skin caused by the vibration of the vocal folds (Figure 1). The sensor is connected to a smartphone (Samsung SM-G310Hn) where an application, the Vocal Holter App (by PR.O.VOICE, Turin, Italy), records the signals with a sampling rate of 22050 Hz and 16 bit of resolution. The App estimates the Sound Pressure Levels (SPLs) of the voice signal at a fixed distance from the speakers' mouth after the calibration procedure with a reference microphone [12].

Figure 1 - An example of long-term voice monitoring in a classroom during P2 with the lighting of SEM device switched on. The contact microphone connected to the smartphone are marked white dots shape.

The voice monitoring procedure was performed according to past works in which the teachers' voice use was performed during their activity for long-terms, i.e. either one week [13] or one year [14] monitoring. In short, the voice monitoring consisted in two steps, that is, in a calibration phase performed in a quiet room of the school and in an activity monitoring performed in the teaching classroom. The calibration procedure was performed before each long-term voice monitoring using a class 1 sound level meter with omnidirectional microphone in air (SLM, XL2, NTi Audio) in the school library, where the A-weighted equivalent background noise level was measured in three different days. The average LA_{eq} value of 37.6 dB (SD = 2.6 dB) was obtained. Each teacher was equipped with the contact-microphone connected to the smartphone and then they were asked to perform the following steps: a) vocalizing for 3 to 5 short times the vowel /a/ with increasing intensity and to repeat this task other two times, alternating few seconds of silence between the repetitions, b) vocalizing a sustained vowel /a/ maintained from 5 to 10 sec and c) performing a free conversation of about 1 min using a comfortable pitch of voice in any position of the room. The calibration steps a) and b) were carried out by each teacher standing in front of the omni-directional microphone in air at the distance of 17cm on axis. Step c), instead, was performed with the teacher standing randomly in the room at one meter from the researcher who supervised the monitoring.

2.3.3 Data processing of voice monitorings

Data were transferred from the sound level meter and smartphone to a personal computer for post-processing. Only the part a) of vowel /a/ scales of the calibration procedure and the time-slot regarding to plenary lesson have been selected at the aim of understanding the teachers' voice use in relation with the noise monitoring with SEM in P1 and P2. For the lessons' monitoring, three different time bands of the day were chosen according to the morning and lunch break, which discriminate different loads for the teacher, that are: morning in the time ranges 8.30-10.30 (M1) and 10.45-12.30 (M2), and afternoon in the time range 14.30-16.15 (A3). Only plenary lesson slots were selected within the entire voice monitorings as this type of vocal activity is the most demanding for teachers, due to a typical phonation time percentage of about 30% according to literature [13, 15]. Time-slots of the plenary lessons have been detected using Audacity software based on the information reported by teachers in the timesheets (described in Section 2.4). According to this procedure, more than one signal has been defined for some long-term voice monitoring, thus a total of 32 signals have been analyzed. The duration of the time-slot varied between 25 min to 120 min each.

Ad hoc MATLAB 2017A scripts were used to estimate the calibration curves of the vowel scale signals recorded by the contact microphone and the SLM for each teacher in each voice monitoring. Then, atemporal alignment between the two signals was performed in order to select the same time segments, containing one or more vowel /a/ scales. With another proper MATLAB script, the voiced and unvoiced frame detection through a suitable RMS voltage threshold was implemented. The RMS values of each evaluated frame was compared to a threshold value defined during the calibration phase, and only the over-threshold frames, $F0$ and SPLs were calculated; conversely, zero values were assigned to the under-threshold frames. As a main output, SPLs occurrence histograms from voiced frames with a bin resolution of 1dB were obtained. Therefore, mean, median, mode and standard deviation values could be calculated from such histograms. The results related to $SPL_{mean,1m}$ are reported in this study.

2.4 Subjective assessments

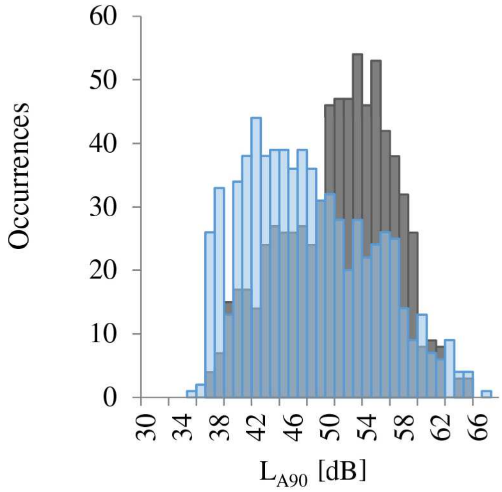
Two questionnaires were administrated to teachers. During each long-term monitoring, the change in activity (e.g. plenary lesson, shared lesson, group activity) was noted by teachers in a timesheet, where they also indicated 1) their perceived vocal status at the end of the daily monitoring compared to the beginning of the day, 2) the perceived degree of noise level in the classroom with respect to the situation of empty room and school at the beginning of the day, 3) the change in voice intensity compared to an ideal condition without background noise and reverberation [8]. The second questionnaire presented in Astolfi et al. [3] was administrated at the end of the noise monitoring campaign to investigate teachers' perception on acoustic quality in relations to several variables. Some questions about the SEM device were added to evaluate how teachers assessed its use as an educational tool. In particular, three questions were related to the purpose of this study since they explored 1) the perceived vocal effort during lessons, and 2) the perceived reduction of vocal effort and 3) the perceived decrease of background noise levels generated by the presence of the lighting feedback of the SEM device.

3. RESULTS

3.1 Statistical analysis

The statistical analysis of the data was performed using SPSS software (v. 20 for Window; IBM Cor, Armonk, NY). The normal distribution of parameters related to background noise levels and teachers' voice was investigated through Shapiro–Wilk test considering a confidence interval of 95% (significance level $\alpha = 0.05$), and an outlier analysis was performed applying the Mahalanobis distance.

The one-tailed Mann-Whitney U Test (MWU) [16] was assessed to investigate statistically significant differences between background noise levels (L_{A90}) measured in two days related to P1 and P2 at the same time of the teachers' voice monitoring. To reduce the number of variables, the occurrence distributions of L_{A90} values related to both phases were selected maintaining some of them as fixed, e.g. teacher, plenary lesson, class and time band. Figure 2 shows an example of improvement in the monitored behavior of children related to their noise production, thus corresponds to a couple of samples where $L_{A90,mean}$ significantly decreased in P2 compared to P1.



	P1 (off)	P2 (on)
Voice monitoring	1	2
Time band	M1	M1
$L_{A90,mean}$ [dB]	50.9	47.8
$L_{A90,median}$ [dB]	52	47
$L_{A90,mode}$ [dB]	53	42
Rank mean	824.7	618.3
MWU p-value	**0.00**	

Figure 2 – An example of occurrences distributions of background noise levels measured in class II C with teacher e), and the results of descriptive statistics and the MWU Test subdivided according to P1 and P2.

3.2 Relationship between background noise levels and voice parameter

Figure 3 shows the relationship between background noise levels ($L_{A90,mean}$) and voice parameter ($SPL_{mean,1m}$) through the best-fit regression lines of the data sample subdivided in Group 1 (n = 17) and Group 2 (n = 15) according to the two phases, respectively. No data was excluded for this analysis.

Looking at the background noise levels, the smaller range of values was obtained for Group 2, (47 dB to 59 dB) compared to Group 1 (51 dB to 62 dB). A slight difference of about 2 dB emerged from the comparison between the range of voice levels of both groups, with the lower range of values found for Group 2. The extreme point of Group 2 was excluded since it largely differed from all other values.

A tendency towards Lombard effect occurred when the lighting feedback of the SEM device was switched off (P1), i.e. an increase in the speech level with background noise level at a rate of about 0.4 dB/dB (Group 1), thus it is within the range indicated by Lazarus [17]. Conversely, a lower tendency to raise voice levels was obtained when a decrease of background noise levels was emerged according to the presence of lighting feedback. Considering the small sample size of this pilot study and the inter-subject differences, the R-squared values were very low for Group 1 ($R^2 = 0.16$) and 2 ($R^2 = 0.05$), and all the obtained relationships can be considered as tendencies only.

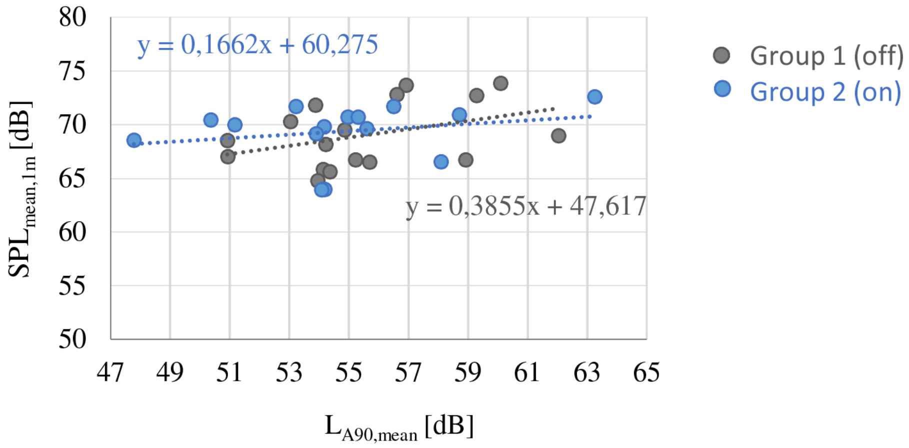


Figure 3 - Best-fit linear regressions between the voice parameter ($SPL_{mean,1m}$) and the mean background noise levels ($L_{A90,mean}$) subdivided in Group 1 and 2 according to P1 and P2.

3.3 The effects of SEM device on background noise levels

Table 2 shows the results related to the analysis on background noise levels performed according to MWU Test. Some data were excluded according to the procedure described in Section 3.1, thus 13 coupled samples were analyzed on a total of 32 data samples. Looking at the comparison between the mean values of background noise levels ($L_{A90,mean}$) measured in P1 and P2 a statistically significant improvement was obtained for 5 of 13 coupled samples (38% in total). The average decrease of $L_{A90,mean}$ values between these coupled samples was of 2.9 dB and a lower range of background noise values was obtained in P2 (47.8 to 56.5 dB) compared to P1 (50.9 to 62.0 dB).

Table 2 – Comparison between $L_{A90,mean}$ measured in P1 and P2 for each coupled sample, and the difference of $L_{A90,mean}$ values between P2 and P1. Significant improvements (p-value < 0.05 according to the MWU Test) are reported in bold. The time band related to the working day are indicated with M1 (8.30-10.30) or M2 (10.45-12.30). The chronological number of the long-term voice monitoring are also specified.

Grade class ID	Teacher ID	Time band	Voice monitoring P1	Voice monitoring P2	$L_{A90,mean}$ [dB] P1	$L_{A90,mean}$ [dB] P2	$\Delta L_{A90,mean}$ [dB]
I L	a	M1	1	2	54.9	55.6	0.7
		M2	**1**	**2**	**62.0**	**56.5**	**- 5.5**
II M	d	M1	1	3	50.9	51.2	0.2
		M2	1	3	54.2	55.0	0.7
		M1	1	4	50.9	53.9	3.0
		M2	1	4	54.2	55.3	1.1
II N	e	**M1**	**1**	**2**	**50.9**	**47.8**	**- 3.1**
		M2	**1**	**2**	**53.9**	**50.4**	**- 3.5**
IV O	f	M1	1	2	54.1	54.2	0.0
		M1	**1**	**3**	**54.1**	**53.2**	**- 0.9**
		M2	1	3	54.4	63.3	8.9
	g	M1	1	2	53.9	54.2	0.2
		M2	**1**	**2**	**53.9**	**50.4**	**-1.6**

3.4 Subjective assessments

Teachers self-estimated that the degree of noise level at the end of the day with respect to the beginning of the day and the empty room were slightly better in presence of SEM device compared to the working day without it, as well as their vocal status. At the end of noise monitoring campaign, 57% of teachers declared that lessons generated a higher vocal effort compared to a normal conversation in absence of noise and reverberation. However, SEM device was considered useful for reduction of vocal effort and improvement of speech, and for decrease of noise levels generated by pupils during plenary lessons for 86% and 72% of teachers, respectively.

4. DISCUSSION AND CONCLUSIONS

The presented work investigated in-field with a structured monitored campaign the reduction of background noise levels generated by the changing of pupils' behavior and its relationship with the teachers' vocal effort, which approach and outcomes miss in the available literature so far. In the framework of this pilot, a statistically significant decrease in background noise levels was measured during plenary lessons suggesting a possible change in pupils' behavior according to the presence of the lighting feedback of the noise monitoring system. Moreover, the usefulness of the SEM device as an educational tool able to improve classroom environment was perceived by most of the teachers involved in the study. These objective and subjective findings are in line with two previous studies [5 7], where the use of visual noise feedback devices was suggested as a possible low-cost solution to reduce noise and improve teaching experience in classroom.

Concerning the relationship between background noise levels and vocal effort the results suggested a tendency of teachers monitored over the weeks to raise their speech level less when the lighting feedback of SEM device was switched in classrooms. Since the statistical power of these results is low, particularly due to the small sample size, further investigations especially with larger numbers of voice monitoring are needed to evaluate the changing in teachers' vocal behavior generated from more awareness on noise conditions and from the reduction of background noise based on the presence of the noise monitoring system with lighting feedback.

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