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UN SISTEMA DI MONITORAGGIO PER CONTROLLARE IL RUMORE ANTROPICO NELLE SCUOLE PRIMARIE INCORAGGIANDO COMPORTAMENTI PROATTIVI

A NOISE MONITORING SYSTEM TO CONTROL ANTHROPIC NOISE LEVELS IN PRIMARY SCHOOL ENCOURAGING PROACTIVE BEHAVIOUR

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RIASSUNTO

Il rumore antropico è la principale fonte di disturbo in ambienti densamente occupati. La letteratura scientifica evidenzia l'importanza di incoraggiare comportamenti proattivi negli occupanti al fine di limitare questa sorgente di rumore. Nel presente lavoro viene validato e applicato un metodo volto a controllare il rumore antropico in 13 aule scolastiche. L'elemento chiave di questo metodo è un sistema di monitoraggio con segnale luminoso che indica il livello di rumore incoraggiando comportamenti proattivi, come l'abbassamento del volume di voce. Un decremento medio dei livelli di rumore di 3.2, 2.2 e 3.3 dB(A) è stato ottenuto con il segnale luminoso nella prima, seconda e terza campagna di monitoraggio.

ABSTRACT

Noise generated by occupants is the most disturbing noise source in densely occupied spaces. International research community is aware of the key role of proactive occupant behaviour to control this noise source. In the present work, a method based on external incentives to control noise is applied and validated in 13 school classrooms. The key factor of this method is a noise monitoring system with lighting feedback that indicates the change of noise levels encouraging proactive behaviours, such as lowering voice levels. The lighting feedback led to a significant average decrease of 3.2 dB(A), 2.2 dB(A) and 3.3 dB(A) in the first, second and third monitoring campaigns, respectively.

Parole chiave: Rumore, comportamento degli occupanti, aule scolastiche, monitoraggio in campo.
Keywords: Noise, occupants' behaviour, school classrooms, in-field monitoring.

1 Introduzione

Noise generated by occupants is largely perceived as the most disturbing noise source in densely occupied environments, such as classrooms [1-3], open-plan offices [4-8], hospitals [9,10] and urban spaces [11-15], causing negative effects on annoyance, performance as well as health and well-being.

Focusing on schools, it is largely known that classroom acoustics may generate challenging environments for both students and teachers, as it influences students' performance [16], speech intelligibility [2], and the vocal effort made by teachers in order to improve intelligibility under noisy condition [17]. A good acoustic environment depends on a combination of factors, such as noise levels, talker-to-listener distance and reverberation. In Italian classrooms average background noise levels ranging from 50 dB(A) to 53 dB(A) were measured during traditional lessons, i.e. when the teacher faced the students [17]. While higher background noise level values – of around 56 dB(A) – were measured during the entire lessons (around 4 h), i.e. a lesson characterized by different types of teaching activities [18]. On the basis of a survey conducted in primary and secondary schools, occupants' behaviour affects acoustic quality in classrooms: higher background noise levels are mainly generated by students' activities, such as talking and moving around the classroom [1, 2].

Research on occupants' behaviour is continuously growing in the energy and building academic communities since it is well known that the interaction of occupants with building systems tends to influence the building energy demand as well as the indoor environment [19]. The behaviour of occupants can also affect the acoustic conditions of environments. For example, noise generated by occupants is largely perceived as the most disturbing noise source in densely occupied environments. In this context, researchers are committed to promoting strategies aimed at motivating the engagement and behavioural changes of people to cope with noise generated by occupants, for example by promoting ICT-based solutions, subjective surveys, awareness campaigns, media communication and lighting feedback systems [10-12]. These latter consist of a system that alternate green, yellow and red colours, according to changes in noise levels in an environment. These systems are already available on the market, however, their adoption is still limited and their ability to reduce noise encouraging proactive behaviour, such as voice lowering or room switching, is not generally understood, in particular over a long-term period.

In Prakash et al. 2011 [20] a lighting feedback system was used in 10 classrooms for a fortnight. In the subjective investigation, students, teachers and the management area perceived a reduction in the noise levels after the installation of the lighting feedback, as well as an overall improvement of the learning environment. In three primary classes over a period of 36 hours, Van Tonder et al. 2016 [21] obtained that a lighting feedback [22] led to a significant decrease in the average noise levels, equal to 1.4 dB(A), comparing the recording periods without and with lighting feedback.

In the present study, a method based on external incentives to control noise is validated in real environments. The key factor of this method is a noise monitoring system with lighting feedback, named SEM (Speech and Sound SEMaphore). The overall aims of the study are: 1) to identify the key factors that make the SEM device different from other devices available on the market and describe the SEM prototypes; 2) to validate the SEM device in primary school classrooms and open-plan offices, adopted as test benches, however a focus on the first ones is only reported in this manuscript; 3) to evaluate how teachers perceive the presence of SEM device as an educational tool.

2 The noise monitoring system with lighting feedback

The SEM device has been developed and patented at Politecnico di Torino. A key difference of SEM against the competitors is the capability to adapt the lighting feedback based on the actual environmental conditions: the colours range from green to yellow and red, led by an adaptive algorithm which does not rely on pre-set limits of sound levels, but links human perception related noticeable variation of Sound Pressure Level (SPL) [23]. The adaptive algorithm is based on the difference between statistical sound levels A-weighted (L_{Ax}) selected according to the intended use of the space. Two versions of algorithm have been developed to best suit the installation environment. The algorithm used in classrooms has been largely validated in the present study. While the algorithm used in open-plan office has been tested during a pilot study performed in a Finnish open-plan office, thus some additional tuning is necessary. Two prototype versions of SEM have been used. The Alpha prototype, applied in classrooms, is a totem based on a transparent panel enlightened by a coloured through-light beam [24]. The device is equipped with a class 2 Sound Level Meter device (ISO-TECH SLM 52N). Data are given in input to the algorithm which, in turn, provides information to a microcontroller board that controls the lighting feedback. Several weaknesses emerged during the validation of the Alpha prototype, for example the lack of flexibility and adaptability caused by physical structure and expensive core components. These weaknesses could seriously jeopardize the large-scale deployment of the SEM device, therefore a Beta prototype has been developed with the clear purpose of designing a low-cost and scalable noise monitoring system for its adaptation in large-scale application. It consists of a small table device with a through-light band, a low-cost electret condenser microphone and a microcontroller board, which wirelessly transfers data to a central server. The calibration by comparison in laboratory and validation in-field has been performed to make the Beta prototype able to measure reliable SPL compared to a class 1 Sound Level Meter and to evaluate its accuracy in the measurements, respectively. The two prototypes are shown in Figure 1.

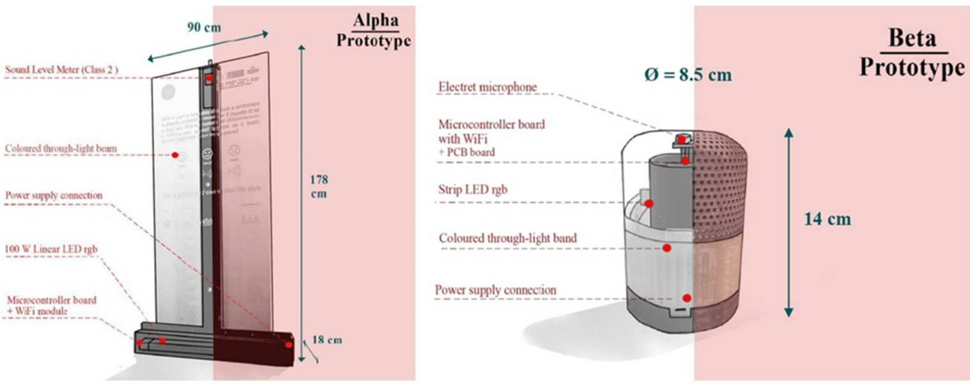

Figure 1 - Diagrammatic representation of Alpha and Beta prototypes, their hardware components and physical dimensions. – Rappresentazione schematica del prototipo Alpha e Beta con indicazione delle componenti hardware e delle dimensioni.

3 Application of the SEM device

3.1 Long-term monitoring campaigns in primary school classrooms

The long-term monitoring campaigns have been performed over 3-school years from 2015-2016 to 2017-2018 in a primary school in Turin (Italy). Objective data on background noise levels has been gathered in the three monitorings. Motivational methods have been introduced in the second and third monitoring campaigns, while the administration of a questionnaire and voice monitoring were performed only in the last monitoring campaign. The results of motivational methods and voice monitoring campaign will not be reported in this manuscript.

3.1.1 Long-term monitoring campaigns in primary school classrooms

The long-term monitoring campaigns involved a primary school dated back to the 1900 and placed in a residential area of Turin (Italy). The classrooms either faced a road with low traffic or the internal courtyard, thus the external noise is not a main source of disturbance. The geometry and materials are similar among the classrooms, which are acoustically treated through perforated plasterboard tiles with air gap from the walls (Figure 2a). The mean reverberation time was 0.9 s and 0.6 s in unoccupied and occupied conditions, respectively, in the mid-frequency range according to [25].

Figure 2 - Primary school (Torino): a) internal view of a type class; b) an example of long-term monitoring in a classroom during P2 with the lighting of SEM was switched on. – Scuola Primaria (Torino): a) vista interna di una classe tipo; b) un esempio di monitoraggio in una classe durante la fase P2 con il segnale luminoso di SEM acceso.

3.1.2 Procedure and data processing

Each campaign has been split in 2 phases distinguished by the absence/presence of the lighting feedback of SEM. In phase 1 (P1) the lighting feedback was switched off and pupils were unaware of the ongoing monitoring to be not influenced by an a-priori information. While, in phase 2 (P2) the lighting feedback was switched on and pupils were aware of the ongoing monitoring, indeed an information campaign was performed by researchers during the first day of this phase to explain the change of the coloured lighting feedback in relations to noise levels produced by pupils themselves. The background noise levels were recorded in both phases through the SEM device. Teachers were invited to switch off/on the prototypes and to note the information in a daily logbook to gather independent variables, such as type of activity and the respective time-slot, own name, number of pupils, day of week and possible noise events coming from outside the classroom.

In addition to the SEM technology, a motivational method based on a constant feedback and/or game-based challenge was applied to promote a constant interaction between pupils and SEM and, finally, the fulfilment of long-term proactive behaviour. The motivational methods were defined according to 1) studies on teaching methods for motivating students [26, 27]; 2) the tendency to adopt several strategies together to cope with noise [10,12]; and 3) teachers' suggestions. The overall A-weighted background noise level generated by pupils was measured during traditional lessons using the A-weighted level exceeded for 90% of the considered time (L_{A90} in dB). The latter was considered to be more appropriate for the anthropic background noise estimation in accordance with previous studies on noise associated with people in classrooms [3,16-18,28] and social gathering places [33]. Moreover, the A-weighted percentile level L_{A90} allows to filter instantaneous noise levels, thus enabling to avoid switching on the red light for instant events, such as door closing or objects falling. The present study has focused on time-slots of traditional lessons, where students sit at their desks and listen to the teacher who is speaking at at her/his desk or close to the blackboard [17]. Higher cognitive efforts for learning are required for students in these lessons, thus low background noise levels are needed. For this reason, the use of SEM has been preliminary addressed for this type of lesson. The time-slots of lesson (ranged between 30 and 120 min) have been manually selected according to the starting and ending points indicated by teachers in the daily logbook.

3.1.3 Subjects and monitoring campaigns

A total of 13 school classes with 290 pupils (6 to 10 years old) and 23 teachers were involved in the long-term monitoring campaigns. Some teachers were excluded from the present study because they filled in the daily logbook approximately or their teaching method was mainly based on group lessons. The overall duration of the monitoring campaigns has been varied over the years from 6 to 16 weeks. The last week of P2 was excluded for two classes because they were involved in activities out of classroom for most days of the week. The first and second monitoring campaigns were carried out from April to June, while the third one lasted from December to April. Table 1 reports the details of each monitoring campaigns according to classes. The latter are indicated with identification codes, e.g. 2A, that will be used in the whole manuscript.

The daily monitoring period corresponded to the working day of about 8 hours, from 8.30 to 16.30 approximately, and was later filter to remove non-teaching activities, such as pupils' arrival and breaks time. A questionnaire was administrated to 8 teachers in all 5 classes at the end of the third monitoring campaign. The Alpha prototype was located in front of pupils in each classroom (Figure 2b) in order to easily provide the lighting feedback. In the class 4O the tables were organized in small groups, thus leading to poor visibility of the lighting feedback for some students.

Table 1 - Main characteristics of each monitoring campaign (MC) subdivided according to classes and the duration in weeks of P1 and P2. – Caratteristiche di ogni monitoraggio (MC) e durata della fase P1 e P2 espressa in settimane.

MC	Duration (week)		ID Class	ID Teacher	Number of teachers	Number of pupils
	SEM off P1	SEM on P2				
1st	2	3/4	2A	-	2	22-25
			3B	-	1	21-22
			4C	-	2	20-26
			5D	-	1	22-26
2nd	2	4	1E	-	3	16-20
			2F	-	2	20-25
			3G	-	2	16-21
			4H	-	3	19-21
3rd	6	10	1I	A B	2	19-24
			1L	H	1	18-22
			2M	C D	2	10-13
			2N	G	1	16-20
			4O	E F	2	22-26

3.1.4 Subjective assessments

In the third monitoring campaign a paper questionnaire was submitted to teachers. It was drawn up according to the questionnaire administrated in [17], and extended to include questions on the use of SEM. A cover letter reported at the beginning of the questionnaire specified its purposes.

The final version was organized in three sections including a total of 24 questions. For each section, the questionnaire investigated: 1) background information, 2) acoustic quality of the classroom and 3) the effectiveness of SEM as an educational tool. The present study is focused on the results of the third section. In this latter, teachers were asked to indicate satisfaction about SEM in terms of noise reduction (Q1), the usefulness of SEM in terms of vocal effort (Q2), attention of pupils to SEM (Q3), long-term improvement of pupils' behaviour (Q4), the usefulness of motivational method (Q5), and the interest in the deploying SEM for noise reduction (Q6). These questions were based on 5-point scale. Open-ended questions and yes/no questions with the option to justify the choice were also used.

4 Application of the SEM device

The statistical analyses of data were performed with MATLAB 2017 and SPSS software. The assumption of normal distribution was assessed through the Shapiro–Wilk test and the boxplots were used for spotting and removing the outliers. Estimates of effect sizes were calculated through Cohen's *d* according to [29-31]. The paired data samples were considered independent in the comparison between the both phases, as long as some variables were different (i.e. daily classroom condition, the contents and activities of the lessons).

In order to evaluate the effect of the SEM lighting feedback on background noise levels, the Mann-Whitney U (MWU) test was applied to investigate the significance of the differences in L_{A90} occurrences distributions related to two days of P1 and P2 controlling the independent variables (named fixed factors). The manual selection of the pair of independent L_{A90} occurrences distributions related to two days of P1 and P2, respectively, was performed according to the characteristic of the fixed factors before the MWU test. The unilateral (right-tailed) MWU test was used to verify whether the hypothesis can be accepted: H1: $M_{off} > M_{on}$ where M_{off} and M_{on} are the mean ranks of L_{A90} occurrences distributions related to the two days of P1 and P2. The pairs of L_{A90} occurrences distributions characterized by a significant reduction of noise when the lighting feedback is switched on are indicated by the term "improvement". An example of this pair of L_{A90} occurrences distributions selected according to the fixed variables is reported graphically in [24]. The fixed factors are type of lesson and its time-band, teacher, number of pupils and day of week. These were selected based on previous studies, in which it emerged that the variation of noise levels was related to type of lesson and number of pupils in classroom [3] and the difference in the use of voice level was associated with morning and afternoon working period [17].

In the second part of the analysis, Wilcoxon signed-rank (WSR) test was applied to investigate the significance of the differences in $L_{A90,mean}$ values between P1 and P2. The pair of $L_{A90,mean}$ values were considered dependent in order to compare two sets of mean scores where the fixed factors are the same. Indeed, data sample of each class consists of the paired mean values of L_{A90} occurrences distributions of P1 and P2.

5 Results

5.1 Effect of SEM on background noise levels

The final sample of L_{A90} occurrences distributions related to P1 and P2 consists of 547 cases. A significant decrease of background noise levels in P2 was obtained for 278 cases – named "improvements" - according to the right-tailed MWU test (p-value < 0.05 with 95% confidence interval). In the other 269 cases, background noise levels increased or did not significantly decrease in P2. These cases are indicated by the term "no improvements".

Table 2 shows that the high comparable percentages of "improvements" were found in the first and third monitoring campaigns (53-56%). Conversely, a strongly lower improvement rate (32%) was obtained in the second monitoring campaign.

Table 2 - The average $L_{A90,mean}$ values of P1 and P2 related to "improvement" (I) and "no improvement" (NI) groups, respectively, and the differences in the averaged $L_{A90,mean}$ values between P2 and P1. Two-tailed *p*-values of the differences between the two phases and the effect size *d* are also stated. Statistically significant differences are reported in bold. – I valori medi di $L_{A90,medio}$ della fase P1 e P2 suddivisi tra i due gruppi: "miglioramenti (I)" e "non miglioramenti (NI)" e la differenza media tra i valori di $L_{A90,medio}$ tra le due fasi. Sono anche indicati i risultati del *p*-values a due code relativi alle differenze tra le due fasi e la dimensione dell'effetto (*d*). Le differenze statisticamente significative sono indicate in grassetto.

MC	ID Class	Percentage of I and NI	Group	$L_{A90,mean}$ SEM off Phase 1	SEM on Phase 2	$\Delta L_{A90,mean}$	*p*-value	*d*
1st	2A	67%	I (10)	50.8 (2.6)	47.6 (2.9)	-3.2	**0.005**	1.61
		33%	NI (5)	47.9 (2.6)	49.3 (3.1)	1.4	NA	NA
	3B	33%	I (3)	49.3 (0.7)	46.7 (0.6)	-2.6	NA	NA
		67%	NI (6)	47.9 (1.6)	48.9 (1.0)	1.0	0.116	-1.02
	4C	65%	I (12)	50.8 (1.9)	47.5 (2.0)	-3.3	**0.001**	1.60
		35%	NI (7)	50.0 (1.5)	52.7 (3.8)	2.6	0.063	-1.15
	5D	59%	I (3)	54.1 (4.8)	51.1 (1.9)	-2.9	NA	NA
		41%	NI (4)	49.7 (2.0)	50.6 (2.2)	0.9	NA	NA
	Total I	56%	Average I	51.0 (2.6)	47.9 (2.5)	-3.2 (0.3)		
	Total NI	44%	Average NI	48.9 (2.0)	50.5 (3.1)	1.6 (0.8)		
2nd	1E	20%	I (2)	54.6 (0.1)	53.1 (1.4)	-1.5	NA	NA
		80%	NI (8)	52.3(3.0)	53.6 (2.4)	1.3	**0.036**	-1.23
	2F	24%	I (6)	53.4 (4.2)	52.0 (4.1)	-1.4	**0.027**	1.65
		76%	NI (19)	51.6 (2.1)	53.5 (2.2)	1.8	**< 0.001**	-1.50
	3G	58%	I (5)	57.7 (5.2)	53.3 (1.2)	-4.4	NA	NA
		42%	NI (5)	49.3 (0.4)	53.0 (1.6)	3.8	NA	NA
	4H	42%	I (5)	57.4 (0.1)	55.1 (1.9)	-2.3	NA	NA
		58%	NI (7)	54.5 (2.9)	56.3 (3.0)	1.8	0.128	-0.89
	Total I	32%	Average I	55.6 (4.1)	53.4 (2.9)	-2.2 (1.4)		
	Total NI	68%	Average NI	52.1 (2.7)	54.0 (2.5)	1.9 (1.1)		
3rd	1I	64%	I (65)	57.7 (2.4)	54.3 (2.7)	-3.4	**< 0.001**	1.56
		36%	NI (38)	54.5 (2.9)	56.3 (3.0)	1.8	**< 0.001**	-1.10
	1L	59%	I (15)	58.4 (2.5)	54.4 (3.0)	-4.0	**0.001**	1.59
		41%	NI (11)	53.7(4.5)	58.3 (2.4)	4.6	**0.004**	-1.53
	2M	51%	I (71)	58.0 (3.2)	54.5 (2.3)	-3.5	**< 0.001**	1.56
		49%	NI (71)	53.4 (4.1)	55.9 (3.8)	2.6	**< 0.001**	-1.42
	2N	56%	I (45)	53.6 (2.6)	50.1 (1.0)	-3.6	**< 0.001**	1.55
		44%	NI (30)	51.3 (2.5)	52.9 (3.6)	1.6	**0.001**	-0.93
	4O	41%	I (36)	57.5 (2.4)	54.6 (2.0)	-2.9	**< 0.001**	1.46
		59%	NI (58)	54.7 (2.7)	57.0 (2.7)	2.2	**< 0.001**	-1.11
	Total I	53%	Average I	57.1 (1.6)	53.8 (1.9)	-3.3 (0.4)		
	Total NI	47%	Average NI	53.7 (1.6)	56.2 (2.1)	2.5 (1.2)		

Note: NA not applicable due to small sample size. The numerosity of the data sample was indicated in the bracket in column "Groups". Standard deviation of the average $L_{A90,mean}$ values was reported in the brackets.

Table 2 also shows the averaged differences between $L_{A90,mean}$ values in P2 and P1 for each class. The significance of such differences is also reported according to the WSR test (*p*-value < 0.05 with 95% confidence interval). The average decrease of $L_{A90,mean}$ values when the lighting feedback is switched on is about 3.2 dB, 2.2 dB and 3.3 dB in the first, second and third monitoring campaigns, respectively. While, the average increase of $L_{A90,mean}$ values in P2 is about 1.6, 1.9 and 2.5 dB in the first, second and third monitoring campaigns, respectively.

Figure 3 shows the distribution of $L_{A90,mean}$ values for each class related to P1. It can be noted, in the absence of the lighting feedback (P1), the typical background noise levels were higher in the “improvement” group compared to “no improvement” group.

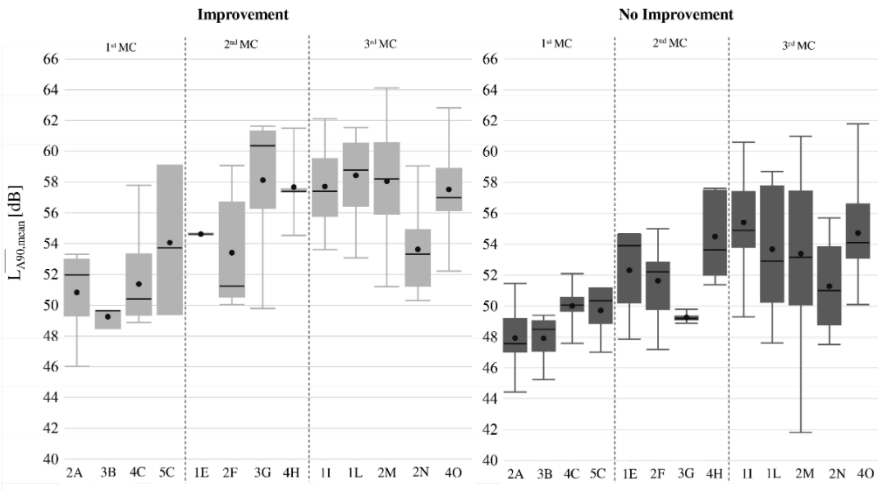

Figure 3 - Boxplots on the distribution of $L_{A90,mean}$ values for each class related to P1 split into “improvement” and “no improvement” groups. The thick line across the box and the dot indicates the median and mean, respectively. – I box plot rappresentati la distribuzione dei dati di $L_{A90,medio}$ relativi alla fase P1 per ogni classe e per i due gruppi: “miglioramenti” e “non miglioramenti”. La linea centrale indica la mediana e il punto il valore medio.

5.2 Effect of SEM on background noise levels

Figure 4 shows assessments of 8 teachers related to the third section of the questionnaire that aimed at better understanding the effectiveness of SEM as an educational tool.

The good degree of satisfaction with SEM in terms of noise reduction (Q1) was obtained in the majority of classes (1I, 1L, 2N), as the evaluation scores are greater or equal than 4. Conversely, lower satisfaction was perceived by teachers of the class 2M and 4O (score of value 2 and 3). A good and middle level of attention of pupils towards the lighting feedback was perceived by teachers of the classes 1I, 2N, 1L and 2M, as the evaluation scores are greater or equal than 3 (Q3). Conversely, one teacher of the class 4O declared that pupils did not pay attention to the variation of the lighting feedback (score of value 2), justifying the low satisfaction with SEM (Q1). These results suggest a qualitative correlation with objective results: lower decrease of average $L_{A90,mean}$ has been obtained in the class 4O (Table 2). Most of the teachers perceived that pupils became more responsible in changing the voice levels over the entire period in which SEM was switched on (Q4); only teacher C reported the score of value 2. Teachers of the class 4O perceived an improvement in pupils’ proactive behaviour over a long-term, despite the level of attention toward the lighting feedback was overall low (Q3). This result could be suggested an increase of pupils’ attention over the monitoring thanks to the introduction of motivational method. The effective of the motivational method was also self-reported by teachers in (Q5), indicating that it helps pupils to do well over the long period, instead to obtain proactive behaviour only at the beginning of the monitoring. The majority of teachers are interested in SEM deployment in classrooms, except one teacher in the class 2M (Q6). In particular, teachers of the class 1I and 4O self-reported higher interest, as the evaluation scores are greater or equal than 4. Thus, it could be assumed that the pupils’ behavioural change on a long-term could be also encouraged by the great interest of the teachers in the use of this device, in addition to motivational method.

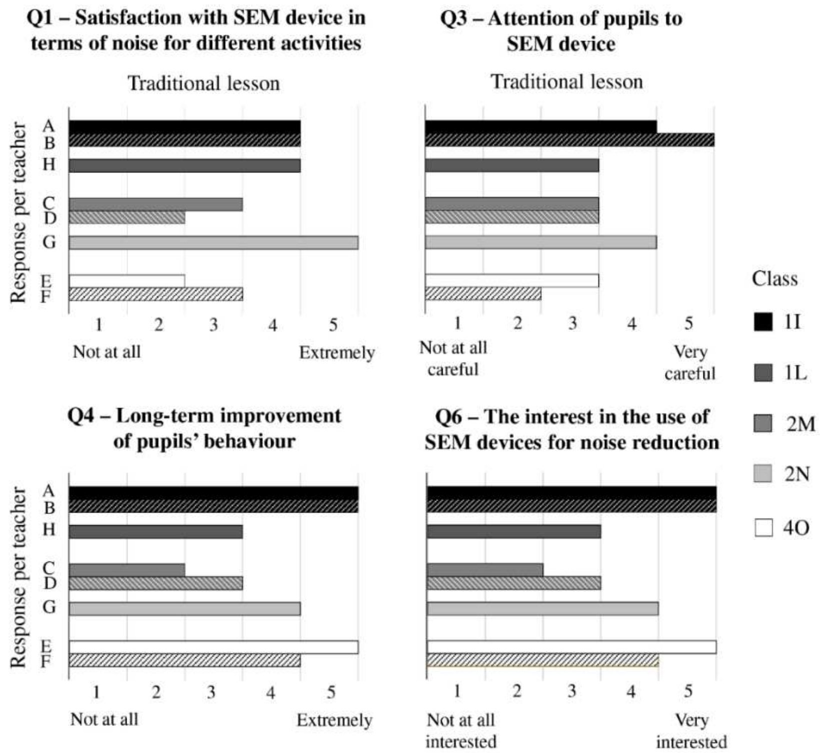

Figure 4 - Responses of each teacher, indicated with capital letters, related to the four questions of section 3 of the questionnaire. The classes are represented by different colours. – Risposte delle insegnanti alla sezione 3 del questionario. Le lettere maiuscole indicano le insegnanti e i colori rappresentano le classi.

6 Discussion

Background noise levels and acoustic characteristics of classrooms are key factors in the learning and teaching processes. A focus on occupant behaviour is emerging in literature to reduce background noise levels and improve acoustic comfort. However, the tendency to enclose active engagement of teachers and pupils is still on a small scale, thus the present study can be considered an exploratory research that sets the base for future works.

Thirteen classes of a primary school in Turin (Italy), for a total of 290 pupils and 25 teachers, were involved over 3 school years in a long-term monitoring campaign.

Independently from the presence of the lighting feedback, the average background noise levels during traditional lessons ranged from 48.0 dB(A) to 51.9 dB(A), 52.2 dB(A) to 56.5 dB(A) and 52.3 dB(A) to 57.3 dB(A) in the first, second and third school year respectively. In the first monitoring, background noise levels were similar to the findings related to traditional lessons emerged in [17], that are 50 dB(A) to 53 dB(A). Conversely, the average background noise levels found in the second and third scholastic year were closer to the highest average background noise levels of 56 dB(A) found in [18] where the noise levels were related to the 4 hours lesson composed of different types of lessons. One consideration can be raised by the latter result: lessons were characterized by random noise levels typical of primary school caused by pupils' behaviour.

A significant decrease of background noise levels was obtained when the lighting feedback was switched on for a total of 51% pairs of independent lessons. These decreases emerged when the starting noise conditions were worse, i.e. the background noise levels were highest in the absence of the lighting feedback. In the remaining cases (49%), background noise levels increased, or the decrease did not reach a statistically significant level. Several reasons may be hypothesised for this result: for example pupils paid smaller attention towards the lighting feedback because the activities required more interaction between them and teachers. The background noise levels were not extremely annoying to require a behavioural change and the engagement of teachers in deploying the SEM device as educational method. However, the decrease of background noise levels was higher compared to their increase when the lighting feedback was switched on, except in two classes.

The noise reduction generated by more aware behaviour of pupils based on the presence of the SEM devices was perceived by the largest number of teachers, indeed they overall declared to be interested to use it as an educational tool. However, these results cannot be generalized due to the small sample size, and it is not possible to compare them with previous study [20], in which a reduction of noise levels and an improvement on the learning environment were found after the installation of the lighting feedback. Overall, some qualitative considerations arose in the present study by the subjective assessments and the discussion between researcheres and teachers. In the class 1I, where teachers were strongly committed in deploying the SEM device as educational tool, a high decrease ($\Delta L_{A90,mean}$ = 3.4 dB) and a low increase ($\Delta_{LA90,mean}$ = 1.8 dB) of background noise level was found in the presence of the lighting feedback. Moreover, the poor visibility caused by table layout in small groups used in the fourth-grade class seems to be the crucial factor in the lower level of pupils' attention towards the SEM lighting feedback and, consequently, in the noise reduction ($\Delta_{LA90,mean}$ = 2.9 dB).

Conclusions

This study explored the abilities of a noise monitoring system with lighting feedback (Speech and Sound SEMaphore) in reducing background noise levels in primary classrooms encouraging pupils' behavioural change. It can be concluded that the activation of the lighting feedback led to a statistically significant average decrease in the first, second and third monitoring campaigns, respectively, for a total of 51% pairs of independent lessons. These decreases emerge when the starting noise conditions are worse, i.e. the background noise levels are highest in the absence of the lighting feedback. In the other pairs of independent lessons (49%), background noise levels increase or do not significantly decrease in the presence of the lighting feedback. However, these increases are lower compared to the decreases of background noise levels when the lighting feedback is switched on. Use of a noise monitoring device with lighting feedback could be a useful education tools to 1) support pupils to control their behaviour during lessons; 2) help teachers to real-time adapt their voice level to noise conditions; and 3) raise awareness of school community on the impact of behavioural changes on improvement acoustic comfort. However, the control of noise levels based on encouraging proactive behaviour remains a challenging task that requires great effort due to the influence of cultural factors, various teaching methods and the need of proactive engagement of teachers in deploying innovative strategies.

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