Relationships Between Classroom Acoustics and Voice Parameters of Teachers at the Beginning and at the End of a School Year

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Abstract
The objective of this longitudinal study is twofold: to determine changes in the voice use of teachers along a school year and to study the relationships between voice and classroom acoustics parameters, which account for the background noise level during the teaching hours too. Thirty-one teachers from two secondary schools in Torino (Italy) were involved at the beginning of a school year and twenty-two of them participated in the monitoring campaign also at the end of the same school year too. Each teacher was asked to perform an interview before each monitoring in order to obtain reference values of conversational voice.

Teachers adjust their voice significantly with noise and reverberation, both at the beginning and at the end of a school year. Moreover, teachers who worked in worst classroom acoustic conditions showed higher voice sound pressure levels at the end of the school year. Based on these results, it is of great importance to improve classroom acoustics to allow teachers reducing their vocal effort during the working hours at school.

Keywords: classroom acoustics, voice parameters, occupational voice, vocal effort, longitudinal study.

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1 Introduction

Recent studies show that individuals who are employed in high-voice use occupations are more likely to develop voice disorders than other working categories [1]. Teachers are one of the occupational groups that make use of voice in a sustained way, exhibiting major possibilities of incurring in the risk of vocal dysfunctions. Several authors that have studied the prevalence of voice problems in teachers agree with the significance of the problem [2-3]. They identify in the vocal load and in the vocal effort two of the most important causes of voice dysfunction [4-6]. Vocal loading is defined as a combination of prolonged voice use and additional factors, such as background noise and classroom

acoustics, which affect intensity and fundamental frequency of phonation [5, 7]. Vocal effort is a physiological magnitude that accounts for the changes in voice production inducted by the distance from the listeners, noise and physical environment [8]. For this reason, long-term monitorings of voice are needed to characterize the vocal behaviour of teachers during working activities. Titze et al [9] studied the vocal fatigue of 31 teachers over a period of two weeks and found that teachers vibrate their vocal folds during teaching activities twice than during non occupational voicing. Hunter and Titze [10] also found an average rise in the sound pressure level of voice (SPL) of 2.5 dB and an average rise in the fundamental frequency (F0) of 10 Hz in occupational versus non occupational voicing. Laukkanen et al [6] found an increase in F0 and SPL during a day at work and describe it as most likely an adaptation to vocal loading. Rantala et al [11] studied teachers' vocal behaviour during a workday and found a tendency for unhealthy teachers to show a smaller increase of their F0 level than their healthy colleagues.
Furthermore, during the last decades a number of research groups have studied the influence of the room acoustics and the background noise on the teacher's voice production. The involuntary tendency of speakers to increase the intensity of their voice as the noise level increases in order to make themselves heard, the well-known Lombard effect [12], is confirmed by several authors [13-15]. As far as the influence of room acoustics parameters on voice parameters is concerned, Brunskog et al [16] found that the average voice level of speakers is closely related to the "room gain" [16], which represents the gain that is given to the speaker's voice due to the reflections in the room. In particular, they found out that teachers tend to speak louder in room with low room gain.
However, no definitive conclusions have been drawn yet on the influence of room acoustics on voice production. Moreover, all these studies were conducted over a period of two weeks or evaluated the change in the teachers' vocal usage during the course of a working day. No study has documented the change in teachers' vocal behaviour along a school year.
All these findings motivated us to investigate through a longitudinal study the vocal behaviour of teachers and noise conditions inside the classrooms along the course of a school year. The vocal behaviour of 31 teachers from two secondary schools that differ in classroom acoustics, location and age of construction were monitored with a portable vocal analyser, namely the Voice Care device, at the beginning of a school year. At the end of the same school year, 22 out of the 31 teachers agreed in being monitored again. The data analysis included the evaluation of the mean, mode and standard deviation of SPL at 1 meter from the teacher's mouth ($SPL_{mean,1m}$, $SPL_{mode,1m}$, $SPL_{sd,1m}$, respectively), the equivalent SPL at 1 meter from the teacher's mouth ($SPL_{eq,1m}$) [17], the mean, mode and standard deviation of fundamental frequency ($F0_{mean}$, $F0_{mode}$, $F0_{sd}$, respectively) and the phonation time percentage ($D_{t\%}$). Two types of voice sample were acquired for each teacher, namely a conversational sample acquired at the beginning of the working day and an occupational sample acquired during teaching activity. The background noise level was also measured for a time interval of 15 minutes during the teachers' voice monitoring and was related to the occupational voice parameters (OVPs). The statistic t-test was performed to compare the mean values of the teachers' OVPs and background noise levels measured during the two stages of the same school year (beginning and end of the school year). Differences between average values of the background noise in the two schools were also investigated in order to evaluate whether different room acoustic conditions affect the noise level. Correlation and regression analyses were used to determine associations and relationships between OVPs and the acoustic conditions inside the classroom, which accounted for the reverberation time and the background noise level.

2 Methods

2.1 Case studies and participants

The two case studies that are considered in this work are two secondary schools located in the Province of Torino (Italy). They mainly differ in location, period of construction, classrooms dimensions and acoustic characteristics of the classrooms.
Institute A was built in early 1800 and is located in the city centre, close to a high vehicular traffic road. School classrooms differ in volume, ranging between 180 m^3 and 320 m^3 for traditional rooms and between 400 m^3 and 1000 m^3 for laboratories. Only a small number of classrooms have absorptive false ceilings.
Institute B, dating back to the second half of 1900, is in a suburban area, nearby a quite road traffic noise street. All the classrooms are characterized by an acoustic treatment consisting in a false ceiling and by volumes of 170 m^3 and 210 m^3.
The acoustic characterization of the classrooms in each school was performed in occupied condition as measured by Puglisi et al [18]. In particular, the reverberation time ($T30_{0.25\text{-}2k\ Hz,occ}$) was averaged in frequency between 0.25 and 2 kHz according to the German standard DIN18041 [19]. This standard specifies a range of acceptable values that is defined as a function of volume (V), mode of use of the room and the typical spectrum of speech. As shown in Table 1, all the $T30_{0.25\text{-}2k\ Hz,occ}$ values in school B are in compliance with the standard ($T30_{0.25\text{-}2\ kHz,occ}$ equal to 0.5 s in both types of classroom) while not in school A ($T30_{0.25\text{-}2\ kHz,occ}$ ranging between 0.7 s and 1.6 s). Therefore, the classroom acoustics in School B is better than in school A.

Table 1 – Classroom characteristics: volume and $T30_{0.25\text{-}2\ kHz,occ}$ measured in occupied (occ) conditions. Standard deviation is reported in brackets. Values in bold indicate the values that are in compliance with the optimal range in the reference.

Classroom characteristics	Reference	Optimal value	School A					School B	
			1.A	2.A	3.A	4.A	5.A	1.B	2.B
Volume [m^3]	/	/	180	210	280	320	400	170	210
$T30_{0.25\text{-}2\ kHz,occ}$ [s]	DIN 18041	$T30opt_{0.25\text{-}2\ kHz,occ} = 0.32\cdot lg\cdot(V/m^3)\text{-}0.17$ +-20%	**0.7 (0.18)**	1.1 (0.26)	0.8 (0.22)	1,4 (0.11)	1.6 (0.29)	**0.5 (0.07)**	**0.5 (0.11)**

Thirty-one teachers from the two secondary schools (21 in school A, four of which who were males, and 10 in school B, two of which who were males) were involved at the beginning of a school year (stage 1) and 22 of them (14 in school A, two of which who were males, and 8 in school B, two of which who were males) also participated at the end of the same school year (stage 2). Their vocal activity was monitored for 2 or 3 working days in each stage. Their age ranged between 38 and 62 years old with a mean of 52.
Only teachers who took part in both the stages have been considered to assess the changes in the voice production along a school year.

2.2 Vocal load and noise monitoring

The vocal load of teachers was monitored using the Voice Care device [20], a portable vocal analyzer that allowed to extract the following parameters: $SPL_{mean,1m}$, $SPL_{mode,1m}$, $SPL_{sd,1m}$, $SPL_{eq,1m}$, $F0_{mean}$, $F0_{mode}$, $F0_{sd}$ and $D_{t\%}$.
For the SPL and $D_{t\%}$ values, males and females were considered together, whereas the F0 statistics were considered separately for the two genders but then only the values for the female subjects were kept since the number of male subjects was too small (only six males).

The vocal monitoring was composed by two samples: conversational and occupational samples of voice. The first sample type was acquired before the teaching activity started, when each teacher was asked to talk for 5 minutes at a conversational pitch. The second sample type, which had a mean duration of about one hour, was taken during a specific teaching activity, namely the plenary lesson.
During the vocal monitoring of teachers, the background noise level in the classroom was evaluated in terms of L_{A90}, which is the A-weighted statistical level exceeded for the 90% of the time under consideration, that is equal to 15 minutes in this study. The L_{A90} was acquired using a class-1 sound level meter placed at 1.2 m from the ground, close to the teacher's desk at a minimum distance of 1 m from the surfaces. All the measurements were performed for a time interval of 15 minutes. In the absence of particular noisy events the 15 minutes recorded were considered representative of the entire activity carried out in the same period.

2.3 Statistical analysis

The statistical analysis of data was carried out with SPSS software (v. 21; SPSS Inc, New York, NY). The Shapiro-Wilk test was applied to understand whether the parameters related to classroom acoustics and teachers' voice were normally distributed. Independent sample t-test was used to assess differences in the mean value of L_{A90} among the two schools and the variation of L_{A90} between the beginning and the end of the school year. Instead, the paired sample t-test was performed to examine the variation in the voice production of teachers along a school year.
The relationship between teachers' OVPs and classroom acoustics was assessed using correlation and regression analysis. To run the regression analysis, values of the dependent variable were grouped and averaged based on independent variable classes. For the $T30_{0.25\text{-}2\ kHz,occ}$ the classes were defined using the just noticeable difference (JND=5%, [21]).This procedure allowed to have well defined and robust groups of data. All the calculations were performed considering a confidence interval of 95%.

3 Results

3.1 Longitudinal study on teachers' voice parameters

The aim of this analysis is to determine the changes in the teacher's voice production between the beginning and the end of a school year. Paired sample t-test was used to compare the mean values of the voice parameters acquired during the two stages. Only teachers monitored for both the stages were considered. Teachers of the two schools were analyzed separately since the acoustic conditions of the two secondary school were different and this could affect in a different way the teachers' vocal behaviour. Table 2 shows the mean and the standard deviation of the mean (standard error, SE) of OVPs and CVPs that changed significantly along the school year. As shown in Table 2, the conversational $SPL_{mean,1m}$ was found to increase at the end of the school year in both the schools, + 4.6 dB and + 3.0 dB in school A and B, respectively. As far as the OVPs are concerned, only in school A significant variations between the two stages were observed; the $SPL_{mean,1m}$ increased on average of 2.3 dB, whereas $D_{t\%}$ and $F0_{sd}$ decreased of 10.3% and 4.5 Hz, respectively.
Table 3 shows the mean value of $SPL_{eq,1m}$, parameter used to classify the vocal effort in ANSI S3.5 [22]. In agreement with this standard it was found that the teachers' vocal effort ranges from "normal" for conversational voicing to "loud" for teaching activity. Not significant variations were observed between the two stages.

Table 2 - Paired sample t-test of occupational voice parameters (OVPs) and conversational voice parameters (CVPs) for the two stages. Significant differences between the two stages (p-value < 0.5) are given in bold and the standard deviation of the mean (standard error, SE) is reported in brackets.

	Voice parameter	School A (14 subjects) Stage 1 Mean	(SE)	Stage 2 Mean	(SE)	Difference (2-1) Mean	(SE)	School B (8 subjects) Stage 1 Mean	SE	Stage 2 Mean	SE	Difference (2-1) Mean	SE
OVPs	$SPL_{mean,1m}$ [dB]	68.3	(1.1)	70.6	(1.0)	**+2.3**	(1.0)	68.4	0.8	68.3	1.3	-0.1	1.5
	$D_{t\%}$ [%]	50.7	(2.5)	40.4	(2.2)	**-10.3**	1.9	37.4	3.1	38.1	4.1	+0.7	3.4
	$F0_{sd}$ [Hz]	61.7	(3.5)	57.2	(3.5)	**-4.5**	1.4	58.4	3.7	57.3	2.7	-1.1	2.8
CVPs	$SPL_{mean,1m}$ [dB]	60.4	(1.6)	65.0	(1.1)	**+4.6**	1.0	58.4	0.7	61.4	0.7	**+3.0**	0.7
	$SPL_{mode,1m}$ [dB]	61.0	(1.7)	65.5	(1.4)	**+4.5**	1.2	58.7	1.2	60.7	1.5	+2.0	1.1

Table 3 – Mean value and standard deviation of the mean (standard error, SE) of $SPL_{eq,1m}$ and classification of the teachers' vocal effort during the occupational voice use while teaching (O) and during the conversational voice use (C) for the two stages based on ANSI S3.5 [22].

	School A (14 subjects) Stage 1 $SPL_{eq,1m}$ [dB] Mean	(SE)	Vocal effort rating	Stage 2 $SPL_{eq,1m}$ [dB] Mean	(SE)	Vocal effort rating	School B (8 subjects) Stage 1 $SPL_{eq,1m}$ [dB] Mean	(SE)	Vocal effort rating	Stage 2 $SPL_{eq,1m}$ [dB] Mean	(SE)	Vocal effort rating
C	64.4	(2.6)	Raised	65.9	(1.9)	Raised	62.0	(0.8)	Normal	61.1	(1.1)	Normal
O	71.7	(1.3)	Loud	72.6	(1.5)	Loud	72.7	(1.4)	Loud	70.8	(1.4)	Loud

3.2 Background noise level

The data acquired from the background noise level monitoring were analysed with two main aims: 1) to determine whether different acoustic characteristics of the classrooms affect the noise level, 2) to evaluate the variation of the noise conditions during the course of a school year. These analyses were carried out using the independent t-test. Since school A was located in the city centre close to high vehicular traffic roads, only the samples of noise acquired in classrooms which overlooked the courtyard were considered. In this way the noise measurements were not affected by the noise coming from outside and could be better related to the acoustic treatment of the classroom.
As shown in Table 4, L_{A90} was not significantly different in the two schools at the beginning of the year while the level of noise was significantly higher in school A, school with worst acoustic conditions, at the end of the school year. As far as the variation of the noise level between the beginning and the end of the school year is concerned, a significant increase of 11.0 dB and 6.6 dB was observed at the end of the school year in school A and B, respectively.

Table 4 - Mean values of L_{A90} measured in the two schools during the two stages. Significant differences among mean values of L_{A90} in the two stages (p-value < 0.05) are identified with symbol *. Values in bold indicate significant different means of L_{A90} between the two schools during the same stage (p-value < 0.05).The standard deviation of the mean (standard error, SE) is reported in brackets.

	L_{A90} [dB] Stage 1 N	Mean	(SE)	Stage 2 N	Mean	(SE)	Difference (2-1) Mean	(SE)
School A	13	48.0	(1.0)	14	**59.0**	(1.0)	+11.0*	(1.4)
School B	16	46.9	(0.9)	12	**53.5**	(0.9)	+6.6*	(1.3)

3.3 Relationships between occupational voice parameters, reverberation time and background noise level

Table 5 shows the most significant part of the correlation matrix between OVPs, $T30_{0.25\text{-}2\ kHz,occ}$, and L_{A90}. A level of correlation coefficient $|r| \geq 0.19$, corresponding to a *p*-value = 0.05 for the absence of correlation t-test given a sample of 110 observations, was chosen for OVPs and $T30_{0.25\text{-}2\ kHz,occ}$, while a level of correlation coefficient $|r| \geq 0.26$, corresponding to a *p*-value = 0.05 for the same test given a sample of 59 observations, was chosen for L_{A90} [23]. Only the coefficients with the *p*-value $\leq$ 0.05 are shown. For OVPs the F0 values were only considered for women, whereas for the SPL and $D_{t\%}$ values males and females were considered together.
For OVPs strong positive correlations (*p*-value < 0.05) was found between $SPL_{mean,1m}$ and $SPL_{mode,1m}$, $SPL_{mean,1m}$ and $SPL_{eq,1m}$, $SPL_{mode,1m}$ and $SPL_{eq,1m}$, $SPL_{sd,1m}$ and $SPL_{eq,1m}$, $F0_{mean}$ and $F0_{mode}$. A weak positive correlation was also found between $F0_{mode}$ and $SPL_{mean,1m}$, $F0_{mode}$ and $SPL_{mode,1m}$, $F0_{mode}$ and $SPL_{eq,1m}$..
For the associations between OVPs and $T30_{0.25\text{-}2\ kHz,occ}$ not strong but only weak positive correlations were found between $SPL_{mean,1m}$ and $T30_{0.25\text{-}2\ kHz,occ}$ and between $D_{t\%}$ and $T30_{0.25\text{-}2\ kHz,occ}$. The weak correlation is most likely due to the large subjective variation of the vocal parameters and to the fact that the correlation analysis does not allow to model the within-subject dependence but just the population average pattern of change. Also for OVPs and L_{A90} a weak positive correlation was found between L_{A90} and $SPL_{mean,1m}$, $SPL_{mode,1m}$, $F0_{mean}$ and $F0_{mode}$. Instead a weak negative correlation was observed between L_{A90} and $SPL_{sd,1m}$. Lastly, a weak positive correlation was found between L_{A90} and $T30_{0.25\text{-}2\ kHz,occ}$.

Table 5 – Correlation matrix between occupational voice parameters, $T30_{0.25\text{-}2\ kHz,occ}$, and L_{A90}. Only correlation with *p*-value lower than 0.05 are shown. Correlation coefficients with significance < 0.01 are marked in bold. r indicates the correlation coefficient and n the number of samples. The OVPs measured only for female are indicated with *F*.

Parameter		$T30_{0.25\text{-}2\ kHz,occ}$ [s]	$SPL_{mean,1m}$ [dB]	$SPL_{mode,1m}$ [dB]	$SPL_{sd,1m}$ [dB]	$SPL_{eq,1m}$ [dB]	$F0_{mean}$ [Hz] *F*	$F0_{mode}$ [Hz] *F*	$F0_{sd}$ [Hz] *F*	D_t [%]	L_{A90} [dB]
$T30_{0.25\text{-}2\ kHz,occ}$ [s]	r	1	0.19							**0.27**	**0.37**
	n	140	140							**140**	**74**
$SPL_{mean,1m}$ [dB]	r		1	**0.89**	**0.34**	**0.86**		**0.36**			**0.38**
	n		154	**154**	**154**	**154**		**110**			**77**
$SPL_{mode,1m}$ [dB]	r			1	**0.37**	**0.73**		0.19			**0.34**
	n			154	**154**	**154**		110			**77**
$SPL_{sd,1m}$ [dB]	r				1	**0.63**					0.24
	n				154	**154**					77
$SPL_{eq,1m}$ [dB]	r					1		**0.30**			
	n					154		**110**			
$F0_{mean}$ [Hz] *F*	r						1	**0.85**	**0.50**		**0.37**
	n						110	**110**	**110**		**59**
$F0_{mode}$ [Hz] *F*	r							1	0.23		**0.37**
	n							110	110		**59**
$F0_{sd}$ [Hz] *F*	r								1		
	n								110		
D_t [%]	r									1	
	n									154	
L_{A90} [dB]	r										1
	n										77

Based on the results of the correlation analysis, the regression analysis was carried out to further understand the relationship between the values of OVPs and L_{A90} to explore the effect of noise on teachers' vocal behaviour (Table 6 and Figure 1); the values of L_{A90} and $T30_{0.25\text{-}2\ kHz,occ}$ to investigate how the background noise level increases with the reverberation time (Table 7); the values of $SPL_{mean,1m}$ and $T30_{0.25\text{-}2\ kHz,occ}$. to evaluate how teachers change their vocal behaviour with the reverberation (Table 8). The regression analysis was run considering separately the two stages. In this way it was possible to establish whether the relationships between the different parameters were the same in the two periods of the school year.

The main outcomes of the above described analyses can be summarised as follows:
1) As far as the influence of the background noise level L_{A90} on OVPs is concerned, an increase in $SPL_{mean,1m}$ and in $F0_{mean}$ with the increase of L_{A90} was observed (Figure 1, Table 6). In particular, it was found a 0.4 dB and a 0.2 dB increase in $SPL_{mean,1m}$ per each 1 dB increase in L_{A90} during stage 1 and stage 2, respectively. It is interesting to note that the increase of $SPL_{mean,1m}$ with the noise at the end of' the school year was slightly lower than that observed at the beginning of the year.
With respect to $F0_{mean}$,it was found to increase at a rate of 2.4 Hz/dB and 2.7 Hz/dB per each 1 dB of increase in the background noise level at the beginning and at the end of the year, respectively. Furthermore the right graph in Figure 1 shows that the regression line relating to stage 2 is below the regression line relating to stage 1. This indicates that after a year of working activity the subjects show a lower F0 in equal noise conditions.

Table 6 - Mean occupational voice parameters ($SPL_{mean,1m}$, and $F0_{mean}$) and their standard deviation of the mean (standard error, SE) versus values of L_{A90} measured during stage 1 and stage 2.

$SPL_{mean,1m}$ vs L_{A90}						$F0_{mean}$ vs L_{A90}					
Stage 1			Stage 2			Stage 1			Stage 2		
L_{A90} [dB]	$SPL_{mean,1m}$ [dB]		L_{A90} [dB]	$SPL_{mean,1m}$ [dB]		L_{A90} [dB]	$F0_{mean}$ [Hz]		L_{A90} [dB]	$F0_{mean}$ [Hz]	
	Mean	(SE)		Mean	(SE)		Mean	SE		Mean	SE
40	64.0	(2.0)	50	69.2	(2.1)	40	226.0	(0.0)	50	211.5	(9.5)
44	67.0	(2.1)	54	69.7	(1.6)	44	193.5	(9.5)	54	201.5	(10.9)
46	65.5	(2.1)	57	70.2	(0.9)	46	203.0	(6.2)	57	231.9	(13.0)
49	67.6	(1.2)	60	70.3	(1.2)	49	226.3	(8.1)	60	230.3	(4.8)
52	68.0	(2.3)	64	72.2	(2.3)	52	251.0	(3.0)	64	247.8	(8.2)
55	71.0	(1.0)	68	72.3	(2.6)	55	238.0	(5.6)	68	251.8	(2.2)

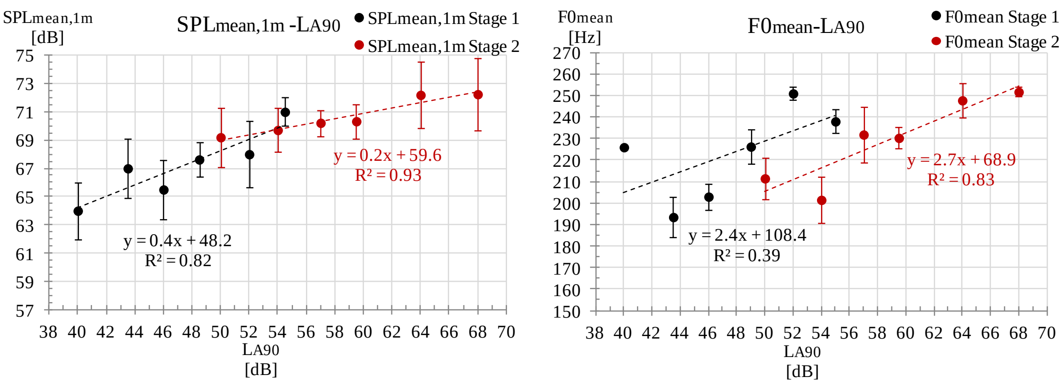
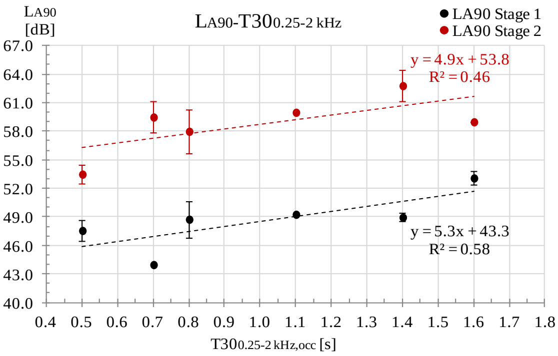


Figure 1 - Best fit linear regression between OVPs ($SPL_{mean,1m}$ and $F0_{mean}$) and L_{A90} monitored during stage 1 and stage 2. Each experimental data on the graph represents the mean value of an average of 5 pairs. Error bars refer to the standard deviation of the mean (standard error, SE).

2) As shown in Table 7, the best fit regression line for the mean L_{A90} vs $T30_{0.25\text{-}2\ kHz,occ}$ indicates an average rate of 5 dB/s in both period of the year proving that the background noise was affected by the reflections that were present in the classrooms. The regression line relating to stage 2 is moved upward with respect to that of the stage 1 indicating an increase of the noise level at the end of the school year.

Table 7 – Mean L_{A90} and standard deviation of the mean (standard error, SE) versus values of $T30_{0.25\text{-}2\ kHz,occ}$, and best fit regression curve at stage 1 and stage 2. Each experimental data on the graph represents the mean value of an average of 10 pairs. Error bars refer to the standard deviation of the mean (standard error, SE).

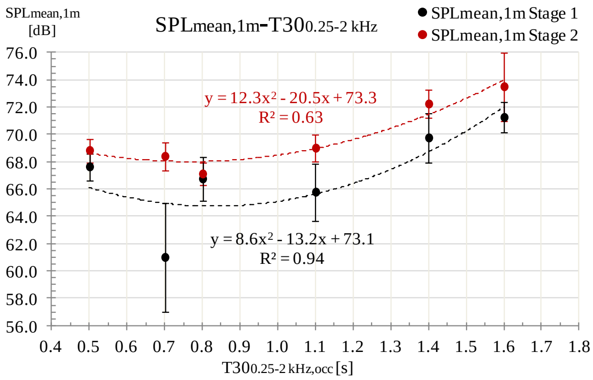
$T30_{0.25\text{-}2kHz,occ}$ [s]	Stage 1 L_{A90} [dB]		Stage 2 L_{A90} [dB]	
	Mean	(SE)	Mean	(SE)
0.5	47.6	(1.1)	53.5	(0.9)
0.7	44.0	(0.0)	59.5	(1.6)
0.8	48.8	(1.9)	58.0	(2.3)
1.1	49.3	(0.2)	60.0	(0.0)
1.4	49.0	(0.4)	62.8	(1.7)
1.6	53.1	(0.8)	59.0	(0.0)



3) Lastly, the mean values of $SPL_{mean,1m}$ were found to be related to the $T30_{0.25\text{-}2\ kHz,occ}$ values through a quadratic regression curve in both stages, as shown in the graph on Table 8. The minimum values of these regression curves correspond to a $T30_{0.25\text{-}2\ kHz,occ}$ of 0.83 s and 0.77 s for stage 1 and stage 2, respectively. Moreover it should be noted that the regression curve relating to the stage 2 is above the curve relating to the stage 1 indicating an increase of $SPL_{mean,1m}$ at the end of the school year.

Table 8 – Mean $SPL_{mean,1m}$ and standard deviation of the mean (standard error, SE) versus values of $T30_{0.25\text{-}2\ kHz,occ}$, and best fit quadratic regression curve at stage 1 and stage 2. Each experimental data on the graph represents the mean value of an average of 10 pairs. Error bars refer to the standard deviation of the mean (standard error, SE).

$T30_{0.25\text{-}2kHz,occ}$ [s]	Stage 1 $SPL_{mean,1m}$ [dB]		Stage 2 $SPL_{mean,1m}$ [dB]	
	Mean	(SE)	Mean	(SE)
0.5	67.6	(0.9)	68.8	(0.9)
0.7	61.0	(4.0)	68.4	(1.0)
0.8	66.8	(1.6)	67.1	(0.8)
1.1	65.8	(2.1)	69.0	(1.0)
1.4	69.8	(1.8)	72.2	(1.0)
0.6	71.3	(1.1)	73.5	(2.5)



4 Discussion and conclusion

The results indicate that teachers speak at higher SPL at the end of a school year during conversational task (average increase = +3.8 dB). This result could be explained as a consequence of the need to use a high voice level during working activity that make teachers using a higher vocal effort during non-occupational activities. During the teaching activities a significant variation of some vocal parameters was observed only in the school with worst acoustic conditions. In this school teachers have shown an average increase of 4 dB in SPL and a reduction of 10% in $D_{t\ \%}$ at the end of the school year. This indicates that teachers who teach in poor acoustic conditions are subject to a greater vocal effort during working activities at the end of the school year and that they decrease the $D_{t\%,}$ in order to reduce the feeling of fatigue.

Measurements of L_{A90} revealed a positive association between L_{A90} and reverberation with a rate of 5 dB/s. Therefore, this result confirms that the background noise is affected by the reflection present in the room and that an acoustical renovation would be needed to reduce the noise levels.

With respect to the influence of background noise level on occupational voice parameters, the Lombard effect was found at a rate of 0.4 dB/dB and 0.2 dB/dB at the beginning and at the end of the year, respectively. This tendency is in agreement with previous studies [12-15] who found the need of teachers to raise significantly their voices under noisy conditions. However the growth rate was smaller than 0.7 dB/dB, which was found by different authors [13-15]. A positive relation between $F0_{mode}$ and L_{A90} was observed at a rate of 2.4 Hz/dB and 2.7 Hz/dB at the beginning and at the end of the year, respectively. Bottalico et al [18] found a similar trend with a rate of 1.0 Hz/dB.

Finally studying the relationships between occupational voice parameters and reverberation was observed that $SPL_{mean,1m}$ is related to the $T30_{0.25\text{-}2\ kHz,occ}$ values through a quadratic regression curve. The minimum value of SPL corresponds to about 0.8 s of $T30_{0.25\text{-}2\ kHz,occ}$ in both the two stages. This result confirms the past study of Bottalico and Astolfi [15][15] where a quadratic curve and a similar optimal value of T30 were found. This relation is also partially in agreement with studies of Brunskog et al [16] which showed a tendency to lower the level of voice with the reverberation. In the present study this tendency only occurs for values of T30 lower than the optimal value, for which more likely the room does not provide sufficient support to the speaker's voice. Instead, when the reverberation is sufficient to support the talker's voice, probably a high reverberation produces a higher level of noise that induces the teachers to raise their level of voice in agreement with the Lombard effect.

The outcomes obtained so far and discussed in this work do not account for the interaction between noise and reverberation on the teachers' vocal behaviour. Furthermore, although a large subjective variation of the vocal parameters is recognized, the voice monitorings were considered together. In this way just the population average pattern of change was obtained. For these reasons future investigations on the combined effect of noise and reverberation on the vocal parameters will be carried out through the multivariate analysis also taking into account the within-subject dependence.

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