Investigations into vocal doses and parameters pertaining to primary school teachers in classrooms

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Investigations into vocal doses and parameters were carried out on 40 primary school teachers (36 females and 4 males) in six schools in Italy, divided into two groups of three, A and B, on the basis of the type of building and the mid-frequency reverberation time in the classrooms, which was 1.13 and 0.79 s, respectively. A total of 73 working-day samples were collected (66 for females and 7 for males), from which 54 traditional lessons were analyzed separately. The average value over the working days of the mean sound pressure level of the voiced speech at 1 m from the teacher's mouth was 62.1 dB for the females and 57.7 dB for the males, while the voicing time percentage was 25.9 and 25.1 %, respectively. Even though the vocal doses and parameters did not differ for the two school groups, the differences in the subjective scores were significant, with enhanced scores in group B. A 0.72 dB increase in speech level per 1 dB increase in background noise level, L_{A90}, was found during traditional lessons, as well as an increase in the mean value of the fundamental frequency with an increase in L_{A90}, at a rate of 1.0 Hz/dB.
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I. INTRODUCTION

Vocal comfort[1] is a psychological magnitude that is determined by those aspects that reduce the vocal effort, while vocal effort[2] is a physiological magnitude that accounts for the changes in voice production introduced by the distance from the listener, noise and physical environment. These changes include voice intensity,[2–7] fundamental frequency,[4–7] duration of speech segments,[4,7] and the spectral distribution of speech.[4,6,7] It is usually quantified objectively by the A-weighted speech level at a distance of 1 m from the mouth,[2] even though this is not an exhaustive measure because it does not consider other voice features beyond voice intensity. Vocal load[8] is the amount of voicing performed by speakers over time. Some vocal dose measures were used by Titze *et al.*[9] as indicators of the long-time exposure of the vocal fold tissue to vibrations, but very few studies have dealt with their application.[10]

A sustained vocal effort, combined with a prolonged vocal load, is assumed to result in increased instances of voice disorders. Voice disorders can derive from a variety of pathological conditions, with effects ranging from a mild disturbance of voice quality to complete loss of the normal speech functions.

Teachers of different types and levels, including teachers of physical education and music, are some of the most affected professional figures.[11–13] Research by the Voice Care Network in the UK, carried out on patients with clinical voice problems, found that 12% of the patients were teachers, while teachers represent only 1.5% of the population.[14] Studies in the U.S. suggest that teachers represent the largest group of subjects with voice disorders.[15] Lejska,[16] through a comprehensive phoniatric examination, found voice disorders in 7.1% of a set of 772 teachers in the Czech Republic, and the percentage rose to 23.5% when cases of voice disorders without any physical pathology were considered. Szeszenia-Dabrowska and Wilczynska[17] have shown that professional voice disorders account for over 21% of all occupational illnesses in Poland.

Many voice disorders are underestimated or even ignored by most people, many of whom are usually unaware of the risks or possible illnesses (e.g., the presence of nodules on the vocal folds). Most voice disorders are caused by chronic and recurrent conditions, which result from an incorrect use of the voice or from poor acoustic conditions in the environments where the voice is used.

Titze *et al.*[18] studied the distributions of continuous voicing periods and silence in 31 teachers over a period of two weeks in order to understand vocal fatigue, in terms of repetitive motion and collision of tissue, as well as the recovery from such mechanical stress. They found that teachers vibrate their vocal folds 23% of the time that they teach, as opposed to 12% of the time that they are not teaching. The total accumulation of voicing time is therefore about 2 h over an 8 h workday.

Hunter and Titze[19] monitored 57 teachers over 2 weeks and compared their occupational weekday voice use with nonoccupational weekday voice use. The main results of their study were: an occupational voicing percentage of 29.9%, which was more than twice that of the nonoccupational voicing; a most frequently occurring occupational voice intensity of 62.5 dB sound pressure level (SPL), only 2.5 dB louder than that of nonoccupational voicing; a rise in the most frequently occurring fundamental frequency of about 10 Hz in occupational versus nonoccupational voicing, suggesting that increased intensity may affect the vocal pitch.

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Masuda *et al.*[20] studied variations in phonation time and intensity in four groups of speakers. In particular they found that office workers exhibited a three times shorter phonation time than teachers and patients with vocal fold nodules (33.6 ± 13.6 min per h and 102.1 ± 22.9 min per h, respectively). Furthermore, among the teachers and patients with a long phonation time, half of their total phonation time was at high intensity.

Vilkman[21] pointed out "bad classroom acoustics" as one of the hazards of voice health. He based this conclusion on the testimony of teachers who had suffered from voice disorders. The Lombard effect, or Lombard reflex,[3] which is the involuntary tendency of speakers to increase the intensity of their voice when speaking in loud noise conditions to enhance audibility is well known, but there are very few studies that link room acoustic parameters to the voice produced by the speaker.

Brunskog *et al.*[22] investigated room acoustic parameters in relation to the increase in the voice sound power level produced by six speakers in six 100–1900 m^3 rooms with a reverberation time of 0.34–1.06 s. They found that the increase in the voice power level produced by a speaker lecturing in a room is correlated to the volume of the room and the gain produced by the reflections in the room, which is objectively defined as "room gain." From this study, it appears that a talker speaks louder in rooms with a low room gain and softer in rooms with a high room gain. A significant correlation between the question concerning whether the subject had to increase her/his voice and an actual increase in voice power was found from the questionnaires that were handed out to the participants, thus showing that the participants were aware of their vocal effort.

Pelegrín-García *et al.*[23] investigated the vocal effort of thirteen male talkers in four differently shaped rooms with different volumes, and a reverberation time of 0.04–5.38 s, with changes in the talker-to-listener distance. The talkers raised their voice intensity by between 1.3 and 2.2 dB as the distance doubled and lowered it at a rate of -3.6 dB per dB of room gain. A significant variation of 4 Hz was also found in the long-term standard deviation of the fundamental frequency among the environments.

Kob *et al.*[24] analyzed the relationships between room acoustics and vocal parameters for 11 teachers in four rooms in a secondary school, two of the rooms before and after having undergone an acoustical treatment. The standard deviation of the mean fundamental frequency decreased by 4 Hz after teaching under "good" room acoustical conditions, and showed a slight increase of 0.4 Hz after teaching under "poor" room acoustical conditions. The voice level was not significantly related to the room acoustics from a statistical point of view.

In short, no definite conclusions have been drawn on the influence of room acoustics on vocal parameters or on the relationships between vocal parameters and vocal comfort. There is still a lack of studies on the vocal load that derives from the long-term monitoring of vocal parameters.

In this study, some vocal doses and parameters of primary school teachers were measured over some working days with the aim of objectively assessing the vocal load. Acoustical measurements were carried out in the classrooms where the teachers were speaking in order to investigate whether the objectively measurable parameters of the rooms could be related to an increase in or modification of the vocal parameters during traditional lessons. Questionnaires were administered to the teachers at the end of the working day and after traditional lessons in order to investigate their perception of their own voices and classroom acoustics, and to discover whether there was any correspondence between the objective and subjective data.

II. SAMPLE OF TEACHERS

Thirty-six female teachers, from 31 to 59 years old, and four male teachers, from 27 to 59 years old, with no special voice training, participated voluntarily in the survey on different working days. All the volunteers were native Italian speakers. The teachers were monitored over one, two, or three working-days (four hours per day) and from these day-samples, traditional lesson samples, with children sitting at their desks and listening to the teacher who is speaking at her/his desk or close to the blackboard, were extracted and analyzed separately.

The monitored teachers work in six primary schools in Turin (Italy). These schools have been divided into two groups, A and B, in relation to the type of building, and each group is composed of three schools (A1, A2, A3 and B1, B2, B3, respectively). The three schools in group A were built at the end of the nineteenth century and are historic, square-court buildings, while the three schools in group B were built in the 70 s and are modern buildings. All the classrooms in the schools face onto a quiet street or onto an internal courtyard.

The average group A classroom height is 4.5 and 3.5 m in group B, and the classroom volumes are about 240 and 160 m^3, respectively. All the rooms are plastered and the floors are covered with ceramics tiles. The two groups of schools are also different as far as the reverberation time is concerned, which, due to the larger volume of the classrooms, is higher in group A than in group B, except for the classrooms in school A3 whose ceilings have been covered with sound absorption material (acoustical plaster), and the reading laboratory in school A2 which has been renovated with special acoustical design features. The acoustic treatment involved placing porous sound-absorption material (rock-wool panels) on the ceiling and upper part of the back and lateral walls, and plaster board panels on the lower part of the walls. After the treatment, the mid-frequency occupied reverberation time in this laboratory was 0.4 s.

Table I reports the main characteristics of the teachers involved in the test, the number of monitored working days, the number of traditional lessons and the acoustic parameters measured in the classrooms during traditional lessons, i.e. the mid-frequency reverberation time, $RT_{\mathrm{mean,500–2\,kHz}}$, and the background noise level, L_{A90}, whose measurement procedures are described in Sec. III B.

III. EXPERIMENTAL PROCEDURE

A. Measurement of the vocal doses and parameters

Before starting the working day, each teacher was supplied with a KayPentax® Ambulatory Phonation Monitor

TABLE I. Characteristics of the investigated teachers and acoustical conditions during traditional lessons.

Subject No.	School	Gender	Age	Age of pupils during lessons	Years of teaching	Subject taught	Number of monitored working-days	Number of monitored traditional lessons	$RT_{mean,500–2\ kHz}$ (s) during traditional lessons	L_{A90} (dB) during traditional lessons
1	A1	Female	38	7–8	≤6	Italian	2	—		
2	A1	Female	43	7–8	≤6	Italian	2	—		
3	A1	Female	37	8–9	≤6	Italian	3	2	1.1/0.4	52.8/43.9
4	A1	Female	54	—	>21	English	3	2	1.6/0.4	51.6/44.3
5	A1	Female	35	7–8	13–18	Maths	2	2	1.0/1.0	45.0/59.0
6	A1	Female	39	7–8	13–18	Maths	2	—		
7	A1	Female	40	6–7	7–12	Italian/Maths	2	2	1.2/1.2	60.6/58.6
8	A2	Female	47	9–10	>21	Italian	2	1	0.4	43.5
9	A2	Female	42	10–11	13–18	Maths	1	—		
10	A2	Female	31	10–11	7–12	Maths	2	1	1.1	41.6
11	A2	Female	34	9–10	≤6	Maths	2	2	1.3/0.4	65.0/64.3
12	A2	Female	58	10–11/8–9	>21	English	2	2	0.4/1.2	43.8/51.6
13	A2	Female	57	9–10	>21	Maths	1	1	0.9	48.2
14	A2	Female	57	7–8	>21	Italian	2	—		
15	A2	Female	54	9–10	>21	Italian	2	3	0.9/0.9/0.4	46.3/48.9/41.4
16	A2	Female	59	9–10	>21	Italian	2	2	1.3/0.4	50.9/42.7
17	A2	Female	34	8–9	≤6	Italian/Maths	1	—		
18	A3	Female	39	10–11	19–21	Italian	1	1	0.5	50.4
19	A3	Male	27	6–7	≤6	Maths	1	1	0.7	54.8
20	A3	Female	37	6–7	≤6	Italian	1	2	0.7/0.7	53.9/50.3
21	A3	Female	56	10–11	>21	Italian	1	1	0.5	54.4
22	A3	Female	48	9–10	>21	Maths	1	1	1.1	54.3
23	B1	Female	46	8–9	>21	Italian	2	1	0.8	
24	B1	Female	34	9–10	7–12	Maths	2	1	0.8	57.5
25	B1	Female	33	7–8	7–12	Maths	2	1	0.8	51.9
26	B1	Male	43	7–8	13–18	Italian	2	1	0.9	52.5
27	B1	Female	49	9–10	>21	Italian	2	1	0.8	54.0
28	B1	Female	56	10–11	>21	Italian	2	3	0.7/0.7/0.7	41.7/47.4/44.8
29	B2	Male	59	8–9	>21	Italian	2	2	0.8/1.1	51.1/49.2
30	B2	Female	38	10–11	≤6	Italian	2	2	0.7/0.7	45.8/54.5
31	B2	Female	47	6–7	19–21	Maths	2	2		44.3/54.4
32	B2	Female	40	7–8	13–18	Maths	2	2	0.8/0.8	50.0/48.3
33	B2	Female	52	9–10	>21	Maths	2	2	0.8/0.9	62.8/57.5
34	B3	Female	55	6–7	>21	Italian	2	1	0.7	42.6
35	B3	Female	58	8–9	>21	Italian	2	2	0.9/0.9	46.3/63.6
36	B3	Female	54	6–7	>21	Maths	2	1	0.7	46.6
37	B3	Male	48	8–9	7–12	Maths	2	3	0.9/0.9/0.9	56.0/43.0/49.6
38	B3	Female	34	8–9	7–12	Italian	1	2	0.9/0.9	45.1/46.6
39	B3	Female	—	7–8	—		2	1	0.8	52.6
40	B3	Female	—	6–7	—		2			

(APM 3200), consisting of an accelerometer, which was positioned on the talker's neck, below the glottis, and an acquisition device that processes the accelerometer signal. Apart from the phonation time, this device provides the fundamental frequency, f_0, and, after calibration, an estimation of the SPL at a distance of 12 cm on-axis from the speaker's mouth; both parameters are sampled every 50 ms.

The calibration was carried out on each teacher using a reference microphone in order to correlate the acceleration level of the skin to the sound pressure level. During the calibration, the speaker was asked to sustain the vowel "/a/", beginning softly and increasing her/his volume to the loudest that she/he could reach. As the phonation was being produced, the software connected to the APM 3200 displayed dots that corresponded to the skin acceleration levels versus sound pressure levels from the reference microphone. The regression line obtained from the dots is used by the software, in post-processing, to estimate the sound pressure level from the skin acceleration level during the monitoring.

According to Titze *et al.*,[9] some different vocal dose measures can be used as indicators of the vocal load. These are obtained from the phonation time, the fundamental frequency and the sound pressure level in front of the teacher's mouth. The simplest vocal dose is the time dose (D_t), expressed in seconds, which is often called the voicing time, and which quantifies the total time that the vocal folds vibrate. The voicing time percentage ($D_{t\%}$) is obtained as the ratio of the time dose to the whole monitoring time. The vocal loading index (VLI), in kcycles, measures the total number of vocal-fold oscillatory periods, while the distance dose (D_d), in m, quantifies the total distance accumulated by the vocal folds during vibration. The energy dissipation dose

(D_e), in J/m^3, is obtained by integrating the power dissipated during phonation, and the radiated energy dose (D_r), in J, is obtained by integrating the power radiated during phonation. The dissipated power is considered an undesirable but necessary by-product of the oscillation of the vocal folds and is caused by the viscoelastic nature of their tissue, while the radiated power represents the sound power when a talker is considered as a sound source.

In order to account for the different duration times of the tests, it is useful to normalize all the doses to the time dose D_t, and $\mathrm{VLI}_{\mathrm{norm}}$, D_{d_norm}, D_{e_norm}, and D_{r_norm} are obtained. These normalized doses give an amount of exposure per second of continuous voiced speech, excluding the entire unvoiced segment. $\mathrm{VLI}_{\mathrm{norm}}$, by definition, corresponds to the mean fundamental frequency expressed in kHz.

The mean sound pressure level of the voiced speech at 1 m from the teacher's mouth, $\mathrm{SPL}_{\mathrm{mean}}$, in decibels, was then calculated by averaging the individual SPLs over only the voice frames, and reporting the level at a distance of 1 m from the speaker's mouth. The mean value of the fundamental frequency, $f_{0,\mathrm{mean}}$, in Hz, was obtained by integrating the f_0 contours over time and dividing by the time dose.

The standard deviations of the SPL and the f_0 were also determined ($\mathrm{SPL}_{\mathrm{sd}}$ and $f_{0,\mathrm{sd}}$, respectively). These quantities give us an evaluation of the voice dynamics and the variation of the intonation, respectively.

Švec *et al.*[25] studied how accurately speech sound pressure levels can be estimated at 30 cm from the speaker's mouth from the vibration of the skin on the neck. Their study was based on measurements on 27 speakers who read the same passages in soft, comfortable and loud voices. The accuracy of the estimation of the $\mathrm{SPL}_{\mathrm{mean}}$ was better than ± 2.8 dB, with 95% of confidence. Variations of approximately ± 2 dB can be expected for traditional SPL voice measurements, with a sound-level meter positioned at a distance of 30 cm, when a subject moves 5 cm towards and away from the sound level meter.[26] On the basis of this finding, an accuracy of ± 2 to ± 3 dB can be considered sufficient for SPL voice and speech measurements.

Similar results were found by Hillman *et al.*[27] who compared fundamental frequency and sound pressure level measurements extracted from a microphone placed 15 cm from the mouth and from a small accelerometer. The measurements were carried out on 24 speakers reading a monologue who had a normal voice, or were mildly, moderately or severely dysphonic. The average errors in the estimation of the sound pressure level from the acceleration signal were 3.2 ± 6.2 dB. The analysis of the fundamental frequency was carried out using the Computerized Speech Lab software. Most of the differences were below 2 Hz, and never exceeded 13 Hz.

B. Measurement of the acoustical parameters in the classrooms

The impulse response was measured in each classroom using a balloon-pop as the impulse source. From this measurement, it is possible to obtain the reverberation time using the backward integration technique.[28] Small differences can be detected between different excitation techniques in the measurement of reverberation time,[29] and these differences are mainly encountered at the lowest frequencies for a balloon-pop.[30] The average occupied reverberation time, from the 500 Hz to 2 kHz octave bands, and over four source-microphone positions, $\mathrm{RT}_{\mathrm{mean,500\text{–}2\,kHz}}$, was obtained for each occupied classroom.

The ambient noise level was monitored in the classroom using a sample period of 1 s, positioning a sound level meter close to the teacher's desk at a height of 1.5 m. The frequency distributions of these levels can be used to separately estimate the noise level close to the teacher during speech and the voice level of the teacher, as suggested by Hodgson *et al.*[31] A mixture of two normal distributions can be fitted to each histogram of the combined A-weighted overall levels: One distribution identifies the noise level and the other the teacher's voice level. The mean value of the noise level distribution, $L_{nA,\mathrm{hist}}$, represents the noise level inside the classroom during teaching activities.

One problem encountered in the present study with this technique is the randomness of the activity noise of children in primary schools, the levels of which are difficult to separate from speech levels. In order to overcome this problem, the measurement interval was limited to traditional lessons, with children sitting at their desks listening to the teacher, who is speaking at her/his desk or close to the blackboard. The overall A-weighted background noise level was estimated during traditional lessons using the above technique and the A-weighted percentile levels, L_{A75} and L_{A90}. No significant variations emerged from the analysis of variance (ANOVA) applications between the L_{A90} and $L_{nA,\mathrm{hist}}$ obtained in the classrooms during traditional lessons. For this reason, L_{A90} was used as the background noise level for the subsequent analyses.

C. Subjective surveys

Two types of questionnaires were administered to the teachers in order to discover whether there was any correlation between the objective and subjective data.

The first type of questionnaire had three questions and it was administered after each teaching activity. It referred to voice intensity and background noise intensity (on a five-point scale in which each step was labeled from 1 to 5, and the first and last also had the opposite descriptors "very low" and "very high") and the manifestation of physical problems (sore throat, aphonia, raucousness, neck stiffness, headache, and general illness).

The second type was administered at the end of the working day. It had 14 questions and was aimed at eliciting general information, information on classroom acoustics and the consequences of classroom acoustics.

The general information included questions on gender, age, mother tongue, years of teaching, and subject taught. After these preliminary questions, the subsequent ones were based on a five- point scale in which each step was labeled from 1 to 5 and the first and last had opposite semantic descriptors. The questions on classroom acoustics covered the following aspects: influence of acoustics on teaching (from "very little" to "a great deal"); noise intensity and noise disturbance (from "very low" to "very high"), i.e., the intensity of the average noise in the classroom and the effect of the disturbance on lessons; noise intensity, noise disturbance and frequency of occurrence (from "very low" to "very high") of different sources perceived by the teachers in the classrooms; reverberation (from "very dry" to "very reverberant"), i.e., reverberation of the sounds and of the teachers' and students' voices; speech comprehension (from "very bad" to "very good"), i.e., how well the teacher comprehended the words spoken by the pupils during traditional lessons; teacher's vocal effort (from "very low" to "very raised"), i.e., the perceived vocal effort of the teacher; acoustical quality satisfaction (from "very dissatisfied" to "very satisfied"), i.e., satisfaction about classroom acoustics. As a last question, the teacher was asked to indicate the frequency (from "never" to "very often") of a list of consequences caused by classroom acoustics, including "loss of concentration," "decrease in students question perception" and "general illness."

IV. RESULTS

The 40 teachers were monitored over one, two or three working-days (four hours per day). A total of 73 working-day samples were collected. From these, 54 traditional lesson samples were taken and analyzed separately. Table I reports the main characteristics of the teachers involved in the test, the number of monitored working days and the number of traditional lessons. The mid-frequency reverberation time, $\mathrm{RT}_{\mathrm{mean,\ 500\text{–}2\ kHz}}$, and the L_{A90} values measured during traditional lessons are also reported.

A. Measurement of the vocal doses and parameters during the working day

The vocal doses $D_{t\%}$, $\mathrm{VLI}_{\mathrm{norm}}$, D_{d_norm}, D_{e_norm}, D_{r_norm} and parameters $\mathrm{SPL}_{\mathrm{mean}}$, $\mathrm{SPL}_{\mathrm{sd}}$, $f_{0,\mathrm{mean}}$, $f_{0,\mathrm{sd}}$ were obtained for each of the 73 working-day samples (66 for the females and 7 for the males). As f_0 is influenced to a great extent by the talker's gender, the male and female subjects were analyzed separately. A normality test was performed in order to apply statistical tools, such as ANOVA.

All the doses and parameters follow a normal distribution, except for D_{d_norm}, D_{e_norm}, and D_{r_norm}. These doses become normal distributed with the following transformations:

$$\mathrm{LD}_{d\_\mathrm{norm}} = 10 \cdot \log\left(\frac{D_{d\_\mathrm{norm}}}{D_{d\_0}}\right),$$
$$\mathrm{LD}_{e\_\mathrm{norm}} = 10 \cdot \log\left(\frac{D_{e\_\mathrm{norm}}}{D_{e\_0}}\right), \qquad (1)$$
$$\mathrm{LD}_{r\_\mathrm{norm}} = 10 \cdot \log\left(\frac{D_{r\_\mathrm{norm}}}{D_{r\_0}}\right),$$

where D_{d_0} is 10^{-4} m/s, D_{e_0} is 10^{-4} mJ/(cm^3 s), and D_{r_0} is 10^{-4} mJ/s.

The uncertainty of the measurement data was then analyzed according to the Guide to the expression of uncertainty in measurement.[32] The "expanded uncertainty," U, associated with an experimental result is obtained by multiplying the "combined standard uncertainty," u_c, by the "coverage factor" k using the following formula:

$$U = k \cdot u_c(y) = k \cdot \sqrt{\sum_{i=l}^{N} u^2(x_i)}, \qquad (2)$$

where $u(x_i)$ is the ith uncertainty contribution due to the variation in a magnitude x_i which represents a factor of influence of the results, and N is the number of the considered uncertainty contributions. The coverage factor k is calculated as the student-t value for a conventional risk of error α of 5% and a number of degrees of freedom, ν, corresponding to $n-1$, where n is the number of data. For a sufficiently large sample k, has a value of about 2.

In this case, only the uncertainty contribution due to reproducibility was calculated as the standard deviation of the mean, according to the following equation:

$$U = k \cdot u_c(y_m) = k \cdot \sqrt{\frac{u^2(y)}{n}} = k \cdot \frac{s(y)}{\sqrt{n}}, \qquad (3)$$

where $u_c(y_m)$ is the combined uncertainty of the sample mean and $s(y)$ is the corresponding standard deviation. The bias of the instrument was not considered because it was not stated in the manufacturer's datasheet, and those reported in literature[25,27] are not related to APM 3200. Nevertheless, the few literature data that are available, related to similar devices, suggest that this bias does not seem to be negligible.

The robustness coefficient r was then calculated to evaluate the goodness of the parameter.[33] This coefficient is defined as the ratio between the mean value of each parameter and its uncertainty, according to the following equation:

$$r = \frac{\mathrm{mean}_{\mathrm{parameter}}}{U}, \qquad (4)$$

where $\mathrm{mean}_{\mathrm{parameter}}$ is the mean value of the considered parameter. When r is higher than unity, the randomness of the parameter can be considered acceptable.

Table II shows the mean value, the uncertainty of the mean and the robustness coefficient of the vocal doses and parameters over the working-day samples. Comparisons have been made between the groups of female and male teachers, the groups of female teachers in schools A and B and the groups of female teachers in schools A and B together, for the morning teaching period and the afternoon teaching period. When groups A and B have been considered in this work, the samples from school A3 and those related to teachers that have only taught in the reading laboratory in school A2 have been excluded since the classrooms are not typical of group A, as they had been acoustically renovated.

The dose values are in the ranges measured by Titze *et al.*,[9] in the laboratory, with three male and three female volunteers who read an excerpt from "Goldilocks" with three different voice inflections, with the exception of $\mathrm{LD}_{r\_\mathrm{norm}}$, which shows a larger variability and the lowest robustness

TABLE II. Mean value, uncertainty of the mean, robustness coefficient, and p-value related to an ANOVA test on the hypothesis of equal means of the vocal doses and parameters over the working-day samples. Comparisons were made between the females and male teachers, between the female teachers in the A and B groups of schools characterized by a different type of building, and between the female teachers in groups A and B together, for the morning teaching period and the afternoon teaching period. The A3 school samples and those of the reading laboratory in school A2 were excluded as they were not typical of group A, since the classrooms had been acoustically renovated.

	Female (66 samples)			Male (7 samples)			
Parameter	Mean	U	Rob. coeff.	Mean	U	Rob. coeff.	p-value
$D_{t\%}$/%	25.9	1.71	15.1	25.1	3.23	7.8	0.78
LD_{d_norm}/dB	38.8	0.51	76.0	36.8	1.04	35.6	<0.05
LD_{e_norm}/dB	36.3	1.06	34.2	34.1	3.37	10.1	0.20
LD_{r_norm}/dB	40.2	2.85	14.1	35.9	9.60	3.7	0.35
SPL_{mean}/dB	62.1	2.41	25.7	57.7	3.85	15.0	0.24
$f_{0,mean}$/Hz	240.0	5.85	41.1	149.6	11.49	13.0	<0.01
SPL_{sd}/dB	1.8	0.07	24.7	1.7	0.13	13.4	0.41
$f_{0,sd}$/Hz	5.4	0.20	26.7	3.4	0.37	9.3	<0.01
	A (29 samples)			*B* (29 samples)			
$D_{t\%}$/%	25.5	2.49	10.24	25.2	2.72	9.25	0.87
LD_{d_norm}/dB	38.8	0.76	50.70	38.6	0.84	45.87	0.71
LD_{e_norm}/dB	36.3	1.53	23.74	35.9	1.78	20.21	0.74
LD_{r_norm}/dB	39.6	4.03	9.81	39.6	4.69	8.45	0.98
SPL_{mean}/dB	62.2	3.79	16.41	61.1	3.93	15.53	0.67
$f_{0,mean}$/Hz	239.4	10.59	22.61	241.4	7.83	30.82	0.76
SPL_{sd}/dB	1.8	0.11	16.22	1.7	0.12	14.28	0.62
$f_{0,sd}$/Hz	5.4	0.34	15.84	5.4	0.32	16.84	0.84
	Morning (32 samples)			Afternoon (26 samples)			
$D_{t\%}$/%	25.3	2.65	9.55	25.4	2.50	10.12	0.98
LD_{d_norm}/dB	38.2	0.78	49.08	39.2	0.78	50.30	0.09
LD_{e_norm}/dB	35.3	1.59	22.18	37.1	1.64	22.56	0.11
LD_{r_norm}/dB	38.1	4.05	9.42	41.4	4.67	8.86	0.28
SPL_{mean}/dB	59.4	3.71	16.00	64.5	3.74	17.26	<0.05
$f_{0,mean}$/Hz	239.9	8.53	28.12	241.1	10.30	23.41	0.85
SPL_{sd}/dB	1.7	0.11	15.14	1.8	0.11	16.01	0.14
$f_{0,sd}$/Hz	5.4	0.32	16.91	5.5	0.35	15.77	0.66

coefficients, due to the exponential dependence on instantaneous SPL values, which are quite variable.

No significant variations in $D_{t\%}$, SPL_{mean}, SPL_{sd}, LD_{e_norm}, or LD_{r_norm} emerge from the ANOVA applications between the genders, while, as expected, significant differences can be seen for the $f_{0,mean}$ and related parameters, i.e., $f_{0,sd}$ and LD_{d_norm}. In particular, the mean value of the $f_{0,mean}$ over the working day samples is 240.0 Hz (U 5.85) for females and 149.6 Hz (U 11.49) for males, respectively.

Significant variations have been detected for SPL_{mean} and $f_{0,mean}$ for female teachers on the basis of their ages and the years of teaching (p-value < 0.1), which are closely correlated (p-value < 0.01). In particular, a decrease in SPL_{mean} of 0.24 dB per year, which can be connected to a reduction in respiratory ability with age that involves a reduction in loudness, has been found. Furthermore, a reduction in $f_{0,mean}$ of about 0.94 Hz per year, which confirms the literature result,[34] can be due to a progressive thickening of the laryngeal epithelium with age.

The subject taught seems to affect the $D_{t\%}$ (p-value < 0.1). In particular, teachers of Italian showed 3% higher values than teachers of Math. On the other hand, the age of the pupils during lessons did not show any influence on the doses or parameters (p-value > 0.1).

No significant difference has been detected between the two school groups A and B, while a significant difference (p-value < 0.05) has been found between the morning and the afternoon teaching periods concerning SPL_{mean}, which increases during the afternoon by about 5 dB.

In Italy, teachers work in two different shifts, from 8.30 a.m. to 12.30 a.m. and from 12.30 a.m. to 4.30 p.m. In order to have a complete description of the teachers' behavior most of them were monitored one morning and one afternoon. The activities in the classrooms are different during these periods since the morning is almost completely dedicated to traditional lessons, with a break in the middle, while the afternoon consists of the lunch break in the canteen, playtime (often in the courtyard) and then traditional lessons.

B. Subjective survey referring to the working day

Table III shows the mean scores and the uncertainty of the mean of the "influence of acoustics on teaching," "noise

TABLE III. Mean scores and uncertainty of the mean of "influence of acoustics on teaching" (IAT) (on a five-point scale from "very little" to "a great deal"), "noise intensity" (NI) and "noise disturbance" (ND) (on five-point scales from "very low" to "very high"), "reverberation" (RT) (on a five-point scale from "very dry" to "very reverberant"), "speech comprehension" (SC) (on a five-point scale from "very bad" to "very good"), "teachers' vocal effort" (TVE) (on a five-point scale from "very low" to "very raised") and the "acoustical quality satisfaction" (AQS) (on a five-point scale from "very dissatisfied" to "very satisfied"), for the female teachers in school groups A and B, characterized by a different type of building, and *p*-value related to an ANOVA test on the hypothesis of equal means.

	A (27 samples)		B (23 samples)		
	Mean	*U*	Mean	*U*	(*p*-value)
IAT	3.07	0.36	2.13	0.40	<0.01
NI	2.93	0.31	2.04	0.36	<0.01
ND	3.07	0.41	1.87	0.40	<0.01
RT	3.22	0.44	1.96	0.33	<0.01
SC	2.70	0.29	3.91	0.34	<0.01
TVE	3.44	0.28	2.83	0.40	<0.01
AQS	2.56	0.38	3.48	0.41	<0.01

intensity," "noise disturbance," "reverberation," "speech comprehension," "teacher's vocal effort," and "acoustical quality satisfaction" for the teachers in the two groups of schools, A and B. In these cases, the ANOVA tests rejected the hypothesis of no differences between the perception of the two groups (p-value < 0.01). Higher scores were achieved in group A, where the classrooms are more reverberant, except for the "speech comprehension" and the "acoustical quality satisfaction" scores, which were higher in group B.

The teachers were asked to evaluate the intensity, disturbance and frequency of occurrence of different noise sources perceived in the classrooms. A statistical analysis showed that these three aspects are closely correlated (p-value < 0.01). Figure 1 shows the mean values and the uncertainty of the mean of the intensity of different noise sources evaluated by the teachers in groups A and B. Significant differences (p-value < 0.05) can be detected between the two groups, with respect to the "students talking in the classroom" (STC), "students moving or shuffling in the classroom" (SMC), and "students talking and moving in the corridor" (STMCO) sources, with the highest scores in group A. The most intense source is STC for both groups. The higher score assigned by group A to the STMCO source is due to the low level of sound insulation of the doors, a recurrent problem in old Italian school buildings.[35]

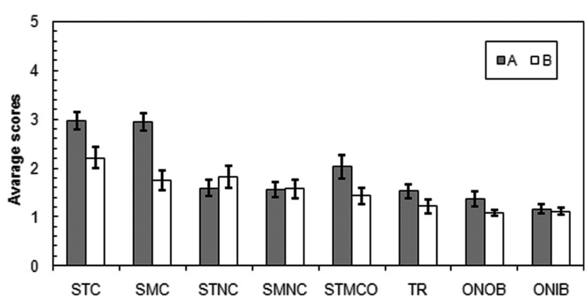

FIG. 1. Mean values and uncertainty of the mean regarding the intensity of different noise sources in the two school groups, A and B, characterized by a different type of building. The five-point scale has the words "very low" (1) and "very high" (5) at the bottom and the top, respectively. The following abbreviations are used for the noise sources: STC for "students talking in the classroom," SMC for "students moving or shuffling in the classroom," STNC for "students talking in the neighboring classrooms," SMNC for "students moving or shuffling in the neighboring classrooms," STMCO for "students talking and moving in the corridor," TR for "traffic," ONOB for "other noise outside the building," and ONIB for "other noise inside the building."

The teachers were also asked to indicate the frequency of a list of consequences caused by poor classroom acoustics, on a five-point scale ranging from "never" to "very often." The highest mean values are shown for group A, but the ranking is similar for the two groups. The most important consequences of poor acoustics are "loss of concentration" and "decrease in students questions perception."

C. Objective and subjective surveys during traditional lessons

Table IV shows the mean values and the uncertainty of the means of the vocal parameters SPL_{mean}, $f_{0,mean}$, SPL_{sd}, and $f_{0,sd}$, the classroom acoustic parameters L_{A90} and $RT_{mean,500–2\ kHz}$ and the subjective scores "voice intensity" (VI) and "background noise intensity" (BNI) during traditional lessons for the female teachers in the two groups A and B and for the female teachers tested both in other classrooms and in the acoustically renovated reading laboratory.

Significant differences can be detected between groups A and B concerning the reverberation time values, "voice intensity" and "background noise intensity" scores (p-value < 0.05). No significant differences have been found between the results obtained in the reading laboratory and

TABLE IV. Mean values, uncertainty of the means and p-value related to an ANOVA test on the hypothesis of equal means of the vocal parameters SPL_{mean}, $f_{0,mean}$, SPL_{sd}, and $f_{0,sd}$, the classroom acoustic parameters L_{A90} and $RT_{mean,500–2\ kHz}$ and the subjective scores "voice intensity" (VI) and "background noise intensity" (BNI) (on a five-point scale from "very low" to "very high"), during traditional lessons for the female teachers of the two A and B groups and for the female teachers tested both in other classrooms and in the acoustically renovated reading laboratory.

	A (12 samples)		B (22 samples)		
	Mean	*U*	Mean	*U*	(*p*-value)
SPL_{mean}/dB	62.1	6.03	60.4	5.21	0.67
$f_{0,mean}$/Hz	246.9	17.34	239.3	9.69	0.38
SPL_{sd}/dB	1.90	0.16	1.74	0.15	0.16
$f_{0,sd}$/Hz	6.02	0.55	5.46	0.45	0.12
L_{A90}/dB	53.2	3.91	50.4	2.87	0.23
$RT_{mean,500–2\ kHz}$/s	1.13	0.13	0.79	0.04	<0.01
VI	3.42	0.50	2.76	0.35	<0.05
BNI	3.25	0.66	2.33	0.48	<0.05
	Other class. (7 samples)		Read. lab. (7 samples)		
SPL_{mean}/dB	65.6	9.07	61.0	8.61	0.41
$f_{0,mean}$/Hz	234.4	24.12	232.4	14.42	0.87
SPL_{sd}/dB	1.98	0.23	1.81	0.22	0.22
$f_{0,sd}$/Hz	5.69	0.77	5.46	0.55	0.58
L_{A90}/dB	52.4	5.32	46.3	7.17	0.13
$RT_{mean,500–2\ kHz}$/s	1.18	0.22	0.4	0.00	<0.01
VI	3.92	0.85	3.83	0.88	0.33
BNI	3.14	1.20	2.50	1.36	0.44

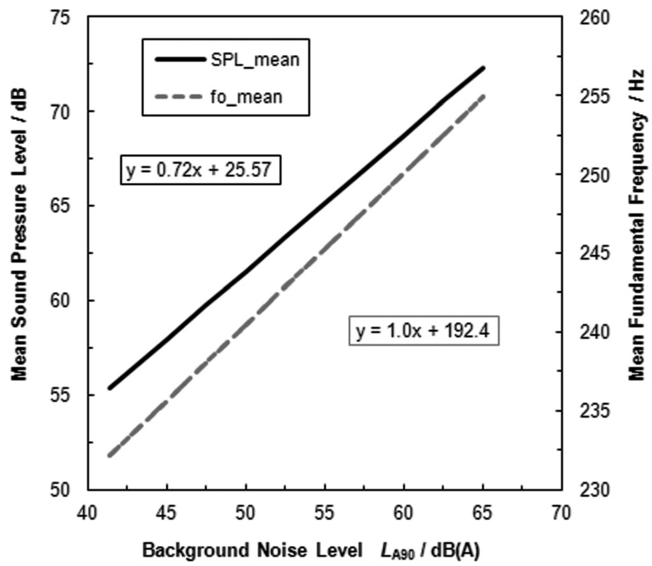

FIG. 2. Best-fit regression lines for the mean sound pressure levels of the voiced speech at 1 m from the teacher's mouth, SPL_{mean}, and mean fundamental frequency, $f_{0,mean}$, values vs background noise levels, L_{A90}, during traditional lessons.

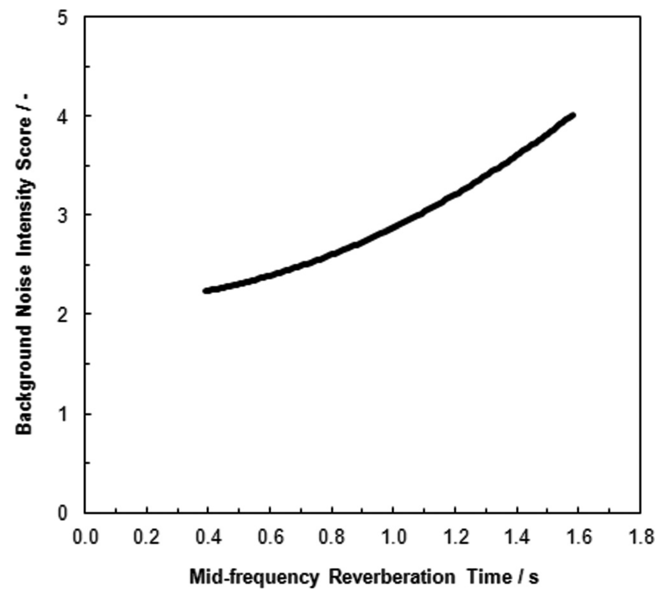

FIG. 3. Best-fit regression curve for the "background noise intensity" scores vs measured mid-frequency reverberation times, $RT_{mean,500\text{–}2\,kHz}$, values. The five-point scale has the words "very low" (1) and "very high" (5) at the bottom and the top, respectively.

those obtained for the same seven teachers in other classrooms, apart from the reverberation time values. A slight, although not significant decrease in SPL_{mean} and $f_{0,mean}$ (and in their standard deviations) has been observed passing from the higher to the lower reverberation time condition.

In order to determine the relationships between the vocal and acoustic parameters and between the subjective and objective scores, some regressions have been carried out considering the whole traditional lesson data samples, but excluding the male teachers.

Figure 2 shows the linear regressions for SPL_{mean} and $f_{0,mean}$ values vs background noise levels L_{A90}. A 0.72 dB increase in speech level per 1 dB increase in noise level can be observed, while the mean fundamental frequency increases with the background noise level at a rate of 1.0 Hz/dB.

Figure 3 shows the regression for the perceived "background noise intensity" scores vs the $RT_{mean,\,500\text{–}2\,kHz}$ values. The best fit for this relationship is a quadratic curve, and on the basis of this result, it emerges that the average background noise intensity score increases with the square of the mid-frequency reverberation time.

Figure 4 shows the regressions for the SPL_{mean} values and the perceived "voice intensity" scores vs $RT_{mean,\,500\text{–}2\,kHz}$ values. The best fit for both relationships is a quadratic curve with a minimum value in correspondence to an $RT_{mean,500\text{–}2\,kHz}$ of about 0.8 s.

From an analyses of the robustness of the regression coefficients, it emerges that all the regressions are well defined, except for the relationship between SPL_{mean} and $RT_{mean,500\text{–}2\,kHz}$.

The teachers were also asked to indicate a series of physical problems perceived at the end of each traditional lesson (multiple indications were permitted), and as a result, 35.2% reported sore throats, 35.2% aphonia, 40.7% raucousness, 18.5% neck stiffness, 11.1% headaches, and 5.6% general illnesses.

V. DISCUSSION

A. Noise and reverberation in the classrooms during traditional lessons

As listed in Table IV, the mean background noise level for the A and B groups of classrooms during traditional lessons is 53.2 dB(A) L_{A90} (U 3.91) and 50.4 dB(A) L_{A90} (U 2.87), respectively. No significant difference has been shown between groups A and B. These values are both higher than the threshold value of 35 dB(A) recommended by WHO (Ref. 36) for teaching activities, and are similar to the ones detected in primary schools by Shield and

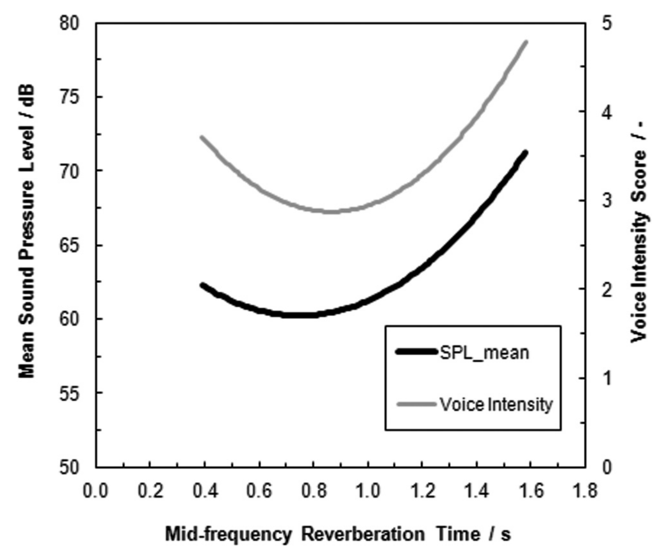

FIG. 4. Best-fit regression curves for the mean sound pressure levels of the voiced speech at 1 m from the teacher's mouth, SPL_{mean}, and "voice intensity" scores vs measured mid-frequency reverberation time, $RT_{mean,\,500\text{–}2\,kHz}$, values during traditional lessons. The five-point scale has the words "very low" (1) and "very high" (5) at the bottom and the top, respectively.

Dockrell,[37] who found an average ambient noise level of 56.3 dB(A) L_{Aeq}, and by Sato and Bradley,[38] who obtained a noise level of 49.1 dB(A) $L_{nA,hist}$.

The measured L_{A90} values do not show any significant difference between groups A and B, but a significant difference can be seen in the perceived "background noise intensity" scores. Significant differences can also be seen between the groups pertaining to the perceived "noise intensity" scores. In particular, higher subjective scores can be found for group A than for group B (see Table III). This behavior could be due to reverberation, which is higher in the group A schools. Likewise, the higher perceived intensity scores of the sources that originate inside the classroom—"students talking in the classroom" and "students moving in the classroom"—for group A than group B (see Fig. 1) could be connected to higher reverberation, which makes these noise sources seem more intense.

This assumption has been confirmed by the quadratic relationship that relates the perceived "background intensity noise" scores to the "reverberation time" values shown in Fig. 3. The perceived "background intensity noise" scores rise with the square of the mid-frequency reverberation time.

B. Vocal effort of the teachers

It is very important to know the level of the teacher's voice, SPL_{mean}, during teaching activities in order to establish a "safe" level for teachers, and then for the resulting signal-to-noise ratios to be examined in order to determine how intelligible the teacher's speech is for the students. As shown in Table II, the mean sound pressure level of the voiced speech at 1 m from the teacher's mouth was on average 62.1 dB (U 2.41) and 57.7 dB (U 3.85) over the working days for the female and male teachers, respectively. Comparable values were obtained during traditional lessons: 61.7 dB (U 3.05) for females and 56.2 dB (U 5.19) for males. These values correspond to a "normal" vocal effort according to the ISO 9921 standard.[2] Sato and Bradley[38] found that the mean voice level of 27 primary school teachers at 1 m from the mouth was 65.3 dB(A) (s.d. 3.7), which is higher than the present finding, while Astolfi and Pellerey[35] found an average value of 64.2 dB(A) (s.d. 4.1) for teachers reading a text in secondary schools.

A significant increase in the mean value of SPL_{mean} of about 5 dB has been found between the morning and the afternoon teaching periods, i.e., from 59.4 dB (U 3.71) to 64.5 dB (U 3.74), and SPL_{mean} is the only parameter that changed during the working day.

The perceived "voice intensity" scores are correlated to the SPL_{mean} values during traditional lessons and both are related to the $RT_{mean,500\text{–}2\,kHz}$ values, through a quadratic regression curve, as shown in Fig. 4. Although the quadratic curve related to SPL_{mean} is not robust, it shows a similar trend to "voice intensity," with a minimum of about 60 dB, corresponding to a mid-frequency reverberation time of about 0.75 s. The minimum value of the regression curve, related to the subjective "voice intensity" scores, corresponds to a reverberation time of about 0.85 s. A range of reverberation time values of between 0.75 and 0.85 s could therefore be considered as an optimal range for a talker in a classroom as it offers good support to the voice. Yang and Bradley[39] found a reverberation time range of about 0.3 to 0.9 s acceptable for speech intelligibility in conditions that were representative of elementary school classrooms. On the basis of their result, the proposed range could also be considered acceptable for speech intelligibility.

C. Lombard effect during traditional lessons

As can be seen in Fig. 2, a 0.72 dB increase in speech level per 1 dB increase in noise level was found during traditional lessons due to the Lombard effect, a result that is in good agreement with the results of Sato and Bradley,[38] who found a 0.72 dB increase in speech level per 1 dB increase in noise level in primary school classrooms.

D. Variation of the fundamental frequency

The mean value of the $f_{0,mean}$ over the working day samples was 240.0 Hz (U 5.85) for females and 149.6 Hz (U 11.49) for males, respectively, as shown in Table II. These values are in the upper range indicated by Titze *et al.*,[9] on the basis of measurements taken on three males and three females who were reading a short passage. The range found by Titze *et al.*[9] was between 200 and 250 Hz for females and between 100 and 150 Hz for males, respectively.

As far as the fundamental frequency standard deviation is concerned, Pelegrín-García *et al.*[23] found a significant increase of 4 Hz when comparing a reverberation room with an anechoic room. Kob *et al.*[24] found that the standard deviation of the mean fundamental frequency decreased by 4 Hz after teaching in good room acoustical conditions (in acoustically treated rooms), and underwent a slight increase, of 0.4 Hz, after teaching in poor room acoustical conditions. Kob *et al.*[24] based their findings on measurements carried out before and after a teaching session, when teachers read a text and pronounced sustained vowels. Table IV shows that the mean values of $f_{0,sd}$ of the present study were slightly lower when the teachers taught in classrooms with lower mid-frequency reverberation times than in those with higher times, even though the differences were not statistically significant.

A lower $f_{0,sd}$ means less variation in speech intonation, and could be due to muscular tiredness. Because of this tiredness, the oscillation of the vocal folds is closer to the mean fundamental frequency. Therefore, a too low reverberation time in a classroom might not be optimal for a talker whose voice is not sufficiently supported by reflections.

Since different results have been found in the literature, further investigations are advisable on the variability of the fundamental frequency with the acoustics of the room. As far as the influence of background noise on the fundamental frequency is concerned, an increase in the fundamental frequency during traditional lessons has been noticed with an increase in background noise level, at a rate of 1.0 Hz/dB. This effect was also found by Quedas *et al.*,[40] who found an increase in the fundamental frequency in a study on eight women without auditory or vocal complaints with an increase in the background noise level of 0 to 90 dB, at a rate of 0.21 Hz/dB.

E. Distance and time dose and safety limit for vocalization

The accumulated distance travelled by the vocal folds may be linked to the safety limit of 520 m, a value that has been derived from industrial standards for hand-transmitted vibrations.[9] If the vocal folds travel about 0.5 m/s during continuous phonation, the safety distance can be reached after about 17 min. Speech, however, consists of voiced and unvoiced pauses, and considering a phonation time of 50%, the safe performance time is about 35 min. In this study, a D_{d_norm} of 0.72 and a phonation time of 25.9% were found on average over the working day samples for the female teachers, while a D_{d_norm} of 0.48 m/s and a phonation time of 25.1% were found for the male teachers, as can be observed in Table II.

The results reported in this study concerning the time dose are similar to those of other studies. Titze *et al.*[18] found that teachers vibrate their vocal folds 23% of the time they teach, compared to 12% of the time they do not teach, Masuda *et al.*[20] measured a mean phonation time of 21.6% on seven elementary teachers over 8 h, while Hunter and Titze,[19] monitored 57 teachers over 2 weeks and found that they vocalized an average of 29.9% of the occupational time.

If the vocal dose data from the present study is assumed, the safe performance becomes 2866 and 4316 s or, approximately, 48 and 72 min, for the female and male teachers, respectively. These values should only be considered an attempt to quantify a continuous safe performance time for vocalization. The silent pauses in vocalization are, in fact, hypothesized to be important to raise the safety limit and prolong the safe performance time.[18] The recovery effect of the voicing pauses is still unknown and constitutes an important research task for future studies.

VI. CONCLUSIONS

This study provides data pertaining to some vocal doses and parameters that were measured on 40 primary school teachers in Italy (36 females and 4 males). The teachers worked in six schools that were divided into two groups of three, A and B, on the basis of the type of building and the average mid-frequency occupied reverberation time in the classrooms, which was 1.13 and 0.79 s, for groups A and B, respectively.

The vocal doses proposed by Titze *et al.*,[9] the mean value of the sound pressure level of the voiced speech at 1 m from the teacher's mouth and of the fundamental frequency as well as the standard deviations of the sound pressure level and fundamental frequency were obtained for 73 working-day samples (66 for females and 7 for males). Fifty-four traditional lesson samples, with children sitting at their desks and listening to the teacher who is speaking at her/his desk, were taken from these day-samples and analyzed separately. The background noise levels, L_{A90}, and the mid-frequency reverberation time, $RT_{\mathrm{mean},500\text{–}2\,\mathrm{kHz}}$, were also measured during traditional lessons.

Questionnaires were administered to the teachers at the end of the working day and after different teaching activities. The questionnaires administered after the traditional lessons allowed relationships to be obtained between the objective and subjective data.

The main findings concerning the monitoring of the working-days may be summarized as follows.

(1) The mean sound pressure level of the voiced speech at 1 m from the teacher's mouth was on average 62.1 dB (U 2.41) and 57.7 dB (U 3.85) over the working days for the female and male teachers, respectively. The corresponding average values of the mean fundamental frequency were 240.0 Hz (U 5.85) and 149.6 Hz (U 11.49), respectively.
(2) The vocal doses and parameters did not differ between the two groups of schools, A and B, and further investigations on their application for vocal load assessment are required. Correlations with vocal pathologies should also be investigated. One of the most important doses is the time dose, which can be related to the recovery effect of the voicing pauses. Voicing time percentages of 25.9 and 25.1 % were found, on average, for the female and male teachers over the day samples, a result that is similar to the results of other studies.
(3) Unlike the vocal doses and parameters, the subjective scores differed significantly between the two school groups. Higher subjective scores related to noise intensity and disturbance, reverberation and teacher's vocal effort were found in group A than in group B, while lower scores were found for speech comprehension and acoustical quality satisfaction.
(4) Significant differences (p-value < 0.05) were found between the morning and the afternoon teaching periods concerning SPL_{mean}, which on average increased during the afternoon by about 5 dB.
(5) The most important consequences of poor acoustics for teachers were a loss in concentration and a decrease in the students questions perception.

The main findings concerning traditional lessons may be summarized as follows.

(1) The mean sound pressure level of the voiced speech at 1 m from the teacher's mouth in a classroom was on average 61.7 dB (U 3.05) and 56.2 dB (U 5.19) for the female and the male teachers, respectively, while the average background noise level, L_{A90}, was 50.6 dBA (U 1.73).
(2) A Lombard effect, corresponding to a 0.72 dB increase in speech level per 1 dB increase in background noise level, L_{A90}, and an increase in the average fundamental frequency with an increase in the background noise level, L_{A90}, was found at a rate of 1.0 Hz/dB.
(3) The perception of background noise intensity increased with the square of the mid-frequency reverberation time.
(4) Even though the measured noise levels, L_{A90}, between the two school groups, A and B, did not differ, the

differences in the perceived noise intensity could be explained by assuming that the noise inside the classrooms with a high *RT* was perceived as being more intense.

(5) A range of mid-frequency reverberation time of between 0.75 to 0.85 s could be considered as an optimal range for a talker in a classroom as it offers good support to the voice.

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