# Effect of noise and reverberation on vocal effort and fatigue of primary school teachers

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## INTRODUCTION

For over one million teachers in Italy their voice is a fundamental work tool and as a result they are thought to be at a higher risk for occupation-related voice disorders than the general population. Vocal emissions seems to be influenced to a great extent by the acoustic conditions of the workplace. In a similar way to the hearing field, literature suggests the use of a dosimetry to measure vocal performances, a field that has not yet been fully explored. The aim of this work is the investigations on the relationships between vocal doses and clinical status, acoustical conditions (noise and reverberation) in the classrooms and subjective evaluations of vocal effort and fatigue. Some vocal dose measures, proposed by Titze & Svec (2003), such as the Vocal Loading Index, the Time Dose, the Distance Dose, the Energy Dissipated Dose and the Energy Radiated Dose, are determined from vocal parameters, in particular fundamental frequency and sound pressure level, collected by the Ambulatory Phonation Monitor (APM 3200) over an entire working day. The clinical examination consisted of a specific anamnesis concerning voice protocol, hearing, functional and professional use of voice (VHI), a logopedic evaluation, Ear, Nose and Throat and phoniatric examination. Two typologies of subjective surveys were administered to the teachers. The first type concerns voice intensity and quality, background noise intensity and physical diseases. The second type consists of 16 questions form aimed at eliciting general information, the experienced vocal symptoms and occurrence and classroom acoustics.

## CASES STUDY

The case studies concern six primary schools in Turin and Beinasco (Italy): the D. Muratori, L. Fontana and R. D'Azeglio schools in Turin, which were built at the end of the nineteenth century, and the E. De Amicis, A. Gramsci and A. Mei schools in Beinasco built in the 70s. All these schools have classrooms which face either onto a quiet street or onto an internal courtyard. The three schools in Turin are historic square-court buildings, while the schools in Beinasco are modern buildings. The classrooms in Turin have vaulted ceiling and a bigger volume in comparison with those of Beinasco. The floor area is about 50 $m^2$ for all the schools, the average height is about 4.5 m in Turin and 3.5 m in Beinasco and the volume ranges from about 240 $m^3$ in Turin and 160 $m^3$ in Beinasco. This study concerns 39 teachers monitored over one, two or three working-days (four hours per day). A total of 66 working-day samples were collected and from these samples 54 traditional lessons were cut and separately analysed. The traditional lesson corresponds to a traditional approach to the class with all the children sitting quietly in front of the teacher who is speaking. Table 1 reports the main characteristics of the investigated teachers, the number of monitored working days, the traditional lessons extracted and the acoustical conditions during traditional lessons.

**Table 1:** Characteristics of the investigated teachers and acoustical conditions during traditional lessons

| Subject | Schools | Age | # of working-days and traditional lessons | RT (s) during traditional lessons | LA90 (dB(A)) during traditional lessons |
|---|---|---|---|---|---|
| 1 | Turin | 38 | 2/- | | |
| 2 | Turin | 43 | 2/- | | |
| 3 | Turin | 37 | 3/2 | 1.1 / 0.4 | 52.8 / 43.9 |
| 4 | Turin | 54 | 3/2 | 1.6 / 0.4 | 51.6 / 44.3 |
| 5 | Turin | 35 | 2/2 | 1.0 / 1.0 | 45.0 / 59.0 |
| 6 | Turin | 39 | 2/- | | |
| 7 | Turin | 40 | 2/2 | 1.2 / 1.2 | 60.6 / 58.6 |
| 8 | Turin | 47 | 2/1 | 0.7 | 54.5 |
| 9 | Turin | 42 | 1/- | | |
| 10 | Turin | 31 | 2/1 | 1.1 | 41.6 |
| 11 | Turin | 34 | 2/2 | 1.3 / 0.4 | 65.0 / 64.3 |
| 12 | Turin | 58 | 2/2 | 0.4 / 1.2 | 43.8 / 51.6 |
| 13 | Turin | 57 | 1/1 | 0.9 | 48.2 |
| 14 | Turin | 57 | 2/- | | |
| 15 | Turin | 54 | 2/3 | 0.9 / 0.9 / 0.4 | 46.3 / 48.9 / 41.4 |
| 16 | Turin | 59 | 2/2 | 1.3 / 0.4 | 50.9 / 42.7 |
| 17 | Turin | 35 | 2/- | | |
| 18 | Turin | 39 | 1/1 | 0.5 | 50.4 |
| 19 | Turin | 27 | 1/1 | 0.7 | 54.8 |
| 20 | Turin | 37 | 1/2 | 0.7 / 0.7 | 53.9 / 50.3 |
| 21 | Turin | 56 | 1/1 | 0.5 | 54.4 |
| 22 | Turin | 48 | 1/1 | 1.1 | 54.3 |
| 23 | Beinasco | 46 | 1/1 | 0.8 | |
| 24 | Beinasco | 34 | 2/1 | 0.8 | 57.5 |
| 25 | Beinasco | 33 | 2/1 | 0.8 | 51.9 |
| 26 | Beinasco | 43 | 1/1 | 0.9 | 52.5 |
| 27 | Beinasco | 49 | 1/1 | 0.8 | 54.0 |
| 28 | Beinasco | 56 | 2/3 | 0.7 | 44 |
| 29 | Beinasco | 59 | 2/2 | 0.8 / 1.1 | 51.1 / 49.2 |
| 30 | Beinasco | 38 | 2/2 | 0.7 / 0.7 | 45.8 / 54.5 |
| 31 | Beinasco | 47 | 2/2 | | 44.3 / 54.4 |
| 32 | Beinasco | 40 | 2/2 | 0.8 / 0.8 | 50.0 / 48.3 |
| 33 | Beinasco | 52 | 2/2 | 0.8 / 0.9 | 62.8 / 57.5 |
| 34 | Beinasco | 55 | 2/1 | 0.7 | 42.6 |
| 35 | Beinasco | 58 | 2/2 | 0.9 / 0.9 | 46.3 / 63.6 |
| 36 | Beinasco | 54 | 2/1 | 0.7 | 46.6 |
| 37 | Beinasco | 48 | 2/3 | 0.9 / 0.9 / 0.9 | 56.0 / 43.0 / 49.6 |
| 38 | Beinasco | 34 | 1/2 | 0.9 / 0.9 | 45.1 / 46.6 |
| 39 | Beinasco | | -/1 | 0.8 | 52.6 |

## SURVEY METHOD

The research, which involves monitoring the vocal performance of primary school teachers and giving teachers a clinical examination, has the aim of detecting the vocal parameters that can be used to assess vocal fatigue and voice recovery in primary school teachers. This is pursued through the investigation of the relationships between vocal parameters and clinical status, vocal parameters and acoustical conditions (noise and reverberation) in the classrooms, vocal parameters and subjective evaluations of vocal effort and fatigue. The adopted protocol has four parts: evaluations of the clinical status of the teachers' voice; measurements of the vocal parameters; subjective surveys; measurements of the acoustical parameters in the classrooms.

## EVALUATIONS OF THE CLINICAL STATUS OF THE TEACHERS

Of the 39 teachers, 32 underwent a clinical examination. This consisted of a specific anamnesis concerning voice protocol, hearing, functional and professional use of voice: the Voice Handicap Index (VHI); a logopedic evaluation related to the respiratory function and voice restoration (GIRBAS Scale) proposed by Dejonckere et al. (1996), Ear, Nose and Throat and phoniatric examination, performed with laryngo-videostroboscopy. Approximately 41 % of the examined subjects showed no sign of disease, while 59 % presented subjective and/or objectively measured pathological symptoms.

## MEASUREMENTS OF THE VOCAL PARAMETERS

Before starting the working day each teacher was supplied with the Ambulatory Phonation Monitor (APM 3200), which is composed of an accelerometer positioned on the talker's neck, below the glottis, and an acquisition device that processes the accelerometer signal. In addition to providing the phonation time, this device also provides the fundamental frequency, and, after calibration, an estimation of the sound pressure level at a distance of 12 cm on-axis from the talker's mouth, both of which are sampled every 50 ms. Calibration is carried out by means of a reference microphone, in order to correlate the skin acceleration level to the sound pressure level. Five different vocal dose measures, proposed by Titze & Svec (2003), are used as indicators of vocal effort and the exposure of the vocal fold tissue to vibrations. These are obtained from the phonation time, the fundamental frequency ($f_0$) and the sound pressure level ($SPL_{m,@1m}$.). Furthermore the standard deviation of SPL (SPLsd) and $f_0$ ($f_0$sd) was evaluated. Vocal doses were measured on 39 teachers (4 males and 35 females) over one, two or three different working days, divided in two half working days (125 samples, 12 for males and 113 for females). The fundamental frequency is significantly influenced by the talker's gender, so the doses were analyzed separately for male and female subjects. In order to compare the different teachers the doses were normalized to the phonation time. The first step was to identify the statistical distribution of each dose and parameter ($D_t$%, $D_{d\_norm}$, $D_{e\_norm}$, $D_{r\_norm}$, $SPL_{m,@1m}$., $f_0$, SPLsd, $f_0$sd), and the possible systematic factors of influence, such as gender and age. All the doses follow a normal distribution except for $D_{d\_norm}$, $D_{e\_norm}$, $D_{r\_norm}$. These doses were transformed in Level Doses with a lognormal function. Table 2 shows the mean value, the uncertainty of the mean (JCGM 100 (2008)) and the robustness coefficients (*r*) (ISO/IEC Guide 43-1 1997) for 39 teachers, divided for males and females, over different half working-days (125 samples) of the doses and parameters. When *r* is higher than 1, the randomness of the parameters can be considered acceptable.

**Table 2:** Mean values, uncertainty of the mean and robustness coefficient of 39 teachers over different half working days (125 samples) of Dt%, Dd_norm, De_norm, Dr_norm, SPLm,@1m., $f_0$, SPLsd and $f_0$sd

| Parameter | Female (113 samples) | | | Male (12 samples) | | |
|---|---|---|---|---|---|---|
| | Mean | U | r | Mean | U | r |
| $D_t$% / m/s | 25.5 | 1.38 | 18.3 | 25.9 | 3.71 | 6.98 |
| $LD_{d\ norm}$ / dB | 66.2 | 0.93 | 71.0 | 63.6 | 1.24 | 51.15 |
| $LD_{e\ norm}$ / dB | 60.7 | 1.91 | 31.6 | 68.7 | 2.51 | 27.32 |
| $LD_{r\ norm}$ / dB | 70.5 | 5.10 | 13.8 | 51.6 | 12.26 | 4.22 |
| $SPL_{m,@1m}$ / dB | 66.4 | 2.08 | 31.8 | 65.8 | 2.68 | 24.59 |
| $f_0$ / Hz | 238.7 | 4.46 | 53.4 | 150.3 | 9.62 | 15.63 |
| SPLsd/ dB | 1.75 | 0.05 | 29.9 | 1.6 | 0.13 | 13.19 |
| $f_0$sd / Hz | 5.36 | 0.15 | 33.9 | 3.4 | 0.35 | 10.06 |

## MEASUREMENTS OF THE ACOUSTICAL PARAMETERS IN THE CLASSROOMS

The impulse response was measured in each classroom using a balloon pop as impulse source. From this measurement, it was possible to obtain the reverberation time using the backward integration technique as suggested by ISO 3382-2 (2008). The ambient noise and speech level were monitored continuously during the working day, using a sample period of 1 s, positioning a sound level meter close to the teacher's desk. The frequency distributions of the levels can be used to estimate the noise level close to the teacher during speech, as suggested by Hodgson et al. (1999). A mixture of two normal distributions can be fitted to each histogram of the combined A-weighted overall levels. One distribution identifies the noise levels ($L_{N\_Hist}$) and the other the teachers' voice levels. One problem encountered in the present study with this technique is the randomness of children activity noise in primary schools, whose levels are difficult to separate from other source levels. In order to overcome this problem, the measurement interval was limited to only lessons with children sitting at their tables and listening to the teacher speaking. The overall A-weighted background noise levels were estimated using the A-weighted percentile levels ($L_{A90}$) from the full sample. Table 3 lists the mean values, uncertainty of the mean of $SPL_{m,@1m}$, $L_{N\_Hist}$, $L_{A90}$, and $RT_{m,500\text{-}2k}$ obtained in Turin and Beinasco, respectively. From this analysis, data from one classroom in school Fontana and all the school D'Azeglio were not considered because acoustically treated (Astolfi et al. 2011). The only significant difference between the two groups is among reverberation times.

**Table 3:** Mean values, uncertainty of the mean and p-values of $SPL_{m,@1m}$, $L_{N\_Hist}$, $L_{A90}$, and $RT_{m,500\text{-}2k}$ obtained in Turin and Beinasco. From this analysis data from the reading laboratory in Fontana school and the D'Azeglio school were not considered because acoustically treated.

| | Turin (28 samples) | | Beinasco (26 samples) | | (p-value) |
|---|---|---|---|---|---|
| | Mean | U | Mean | U | |
| $SPL_{m,@1m}$ /dB | 62.1 | 5.53 | 59.2 | 4.11 | 0.44 |
| $L_{N\ ist}$ /dB | 51.8 | 3.20 | 52.4 | 2.38 | 0.77 |
| $L_{A90}$ /dB | 53.2 | 3.59 | 50.4 | 2.25 | 0.18 |
| $RT_{m,500\text{-}2kHz}$ /s | 1.13 | 0.12 | 0.82 | 0.04 | <0.01 |

## SUBJECTIVE SURVEYS

In order to find any correlations between the vocal parameters and the perceptions of the teachers' own voice statuses, two typologies of subjective surveys were administered to the teachers. The first type consists of a 4-question form, administered after each teaching activity. It concerns voice intensity and quality, background noise intensity and physical diseases (sore throat, aphonia, raucousness, neck stiffness, headache and general illness). Different teaching activities were performed in periods of around two hours at a time. The second type of survey, consists of a 16-question form aimed at eliciting general information, vocal symptoms experienced with their frequency, and classroom acoustics. It was administered at the end of the working day. Most of the answers referred to a 5-point scale in which each step was labelled from 1 to 5 and the extremes with opposite semantic descriptors.

In the second type of questionnaire the teachers were asked to indicate intensity, disturbance and occurrence of different noise sources, and the frequency of a list of perceived consequences caused by poor classroom acoustics experienced in the classrooms. Noticeable differences between schools in Turin and Beinasco on all the questions ($p<0.01$) were observed. As shown in Figure 1 the trends are similar but the scores show lower values in Beinasco. 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 Neighbouring Classrooms," SMNC for "Students Moving or shuffling in the Neighbouring 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 list of perceived consequences consists of "Decrease in perception of the students' questions" (DPQ), "Loss of concentration" (LC), "Headache" (H), "General Illness" (GI).

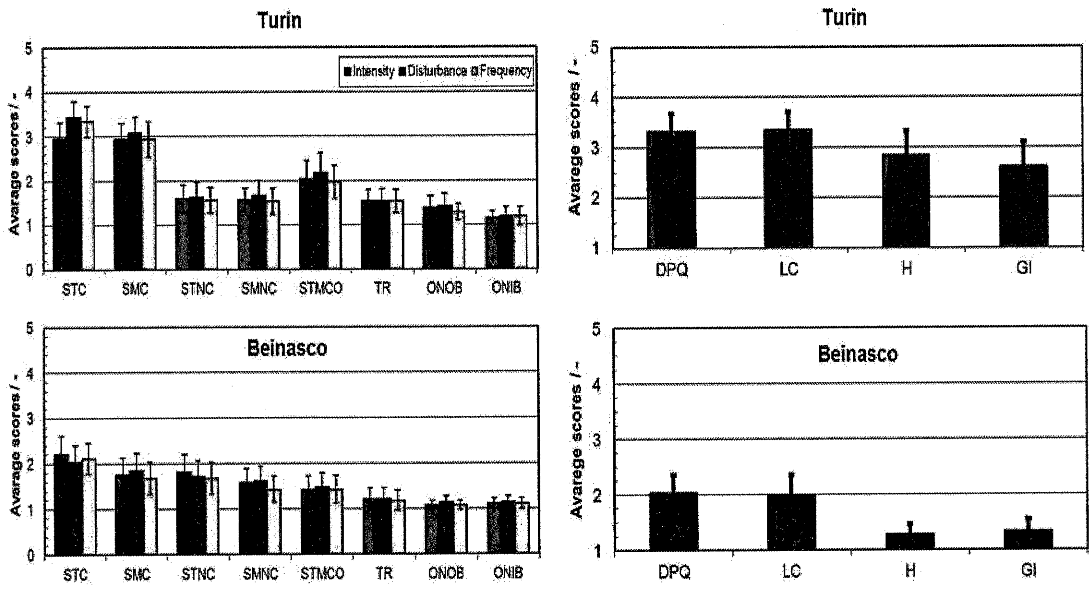


**Figure 1:** Intensity, disturbance and occurrence of different noise sources, and frequency of a list of perceived consequences caused by poor classroom acoustics experienced by the teachers in the classrooms. The five-point scale is from "never" (1) to "very often" (5).

Noticeable differences between schools on the perception of some acoustical factors were observed. The mean scores and the uncertainty of the mean of "Influence of acoustics on teaching" (IAT), "Noise Intensity" (NI), "Noise Disturbance" (ND) (on a 5-point scale from "very low" to "very high"), "Reverberation" (RT) (5-point scale from "very dry" to "very reverberant"), "Speech Comprehension"(SC) (on a 5-point scale from “very badly” to “very well”), “Teachers’ Vocal Effort” (TVE) (5-point scale from “very low” to “very raised”) and the “Acoustical Quality Satisfaction” (AQS) (5-point scale from “very unsatisfied” to “very satisfied”) are shown in Table 4.

In all these cases the ANOVA tests reject ($p<0.05$) the hypothesis of no differences between the perceptions of the two groups, and higher scores are achieved in Turin, where the classrooms are more reverberant, except for the Speech Comprehension and Acoustical Quality Satisfaction. It is interesting to note that differences related to the scores about vocal effort and noise intensity and disturbance perceived by teachers in the two groups of schools are subjectively significant but not objectively.

**Table 4:** Mean scores and uncertainty of the mean of “Influence of acoustics on teaching” (IAT), “Noise Intensity” (NI), “Noise Disturbance” (ND) (on a 5-point scale from “very low” to “very high”), “Reverberation” (RT) (5-point scale from “very dry” to “very reverberant”), “Speech Comprehension”(SC) (on a 5-point scale from “very badly” to “very well”), “Teachers’ Vocal Effort” (TVE) (5-point scale from “very low” to “very raised”) and the “Acoustical Quality Satisfaction” (AQS) (5-point scale from “very unsatisfied” to “very satisfied”) for the schools in Turin (a, b and c) and or the schools in Beinasco (d, e and f), together with p-value from a t-tests for the difference of the mean.

| | Turin (32 samples) | | Beinasco (34 samples) | | (p-value) |
|---|---|---|---|---|---|
| | Mean | U | Mean | U | |
| IAT | 3.09 | 0.34 | 2.14 | 0.37 | <0.05 |
| NI | 2.91 | 0.29 | 2.21 | 0.37 | <0.05 |
| ND | 3.03 | 0.36 | 2.00 | 0.38 | <0.05 |
| RT | 3.19 | 0.42 | 2.04 | 0.31 | <0.05 |
| SC | 2.75 | 0.28 | 3.89 | 0.34 | <0.05 |
| TVE | 3.44 | 0.24 | 3.00 | 0.38 | <0.05 |
| AQS | 2.53 | 0.37 | 3.32 | 0.42 | <0.05 |

## OBJECTIVE ACOUSTICAL MEASUREMENTS IN THE CLASSROOMS AND CORRELATIONS WITH VOCAL PARAMETERS, SUBJECTIVE DATA AND CLINICAL EXAMINATION

Table 1 reports the midfrequency occupied reverberation time and the $L_{A90}$ values in the classrooms investigated during traditional lessons. The number of students in each classroom was between 15 and 25. The reverberation time ranges from 0.5 s, in the L. Fontana reading laboratory, to a mean value of 0.9 s, s.d. 0.2, in the other classrooms. Figure 2 shows the relationships between $SPL_{m,@1m}$ and $L_{A75}$ and $L_{A90}$ values in order to check the Lombard effect. A 0.70-0.72 dB increase of speech level per 1 dB increase of noise level was found. The present result agrees with that of Sato & Bradley (2008) who found a 0.72 dB increase of speech level per 1 dB increase of noise level in primary school classrooms. Figure 3 shows the relationship between $f_{0,mean}$ and $L_{A90}$. The fundamental frequency increases with the increasing in background noise at a rate of 1.2 Hz/dB.

A correlation matrix has been calculated in order to obtain the most significant correlations ($p<0.01$) between the subjective scores expressed after each teaching activity and the acoustical and vocal parameters. “Voice intensity” is strongly correlated with $SPL_{m,@1m}$ (as shown in Figure 4), and with the three dose levels $LD_{d,n}$, $LD_{e,n}$ and $LD_{r,n}$, while “background noise perceived intensity” with “voice intensity” and with $L_{A75}$ and $L_{A90}$. Furthermore Figure 5 shows the relationship between “background noise perceived intensity” and the mid-frequencies reverberation time. The best fit for this relationship is a quadratic curve, and this means that the noise perception increases with the square of the reverberation time. A correlation analysis was performed between the causes and effects related to the vocal pathology. It necessary to underline that the sample number was not sufficient to analyse the synergy of different causes. The grade of pathology was evaluated in a 6 points scale, from the absence of pathology to the presence of vocal nodules. From this first analysis it is possible to state that the main causes of a vocal pathology are $D_t$%, smoking and genetic predisposition, where $D_t$% represents both the vocal load in temporal terms and the speed of speech.

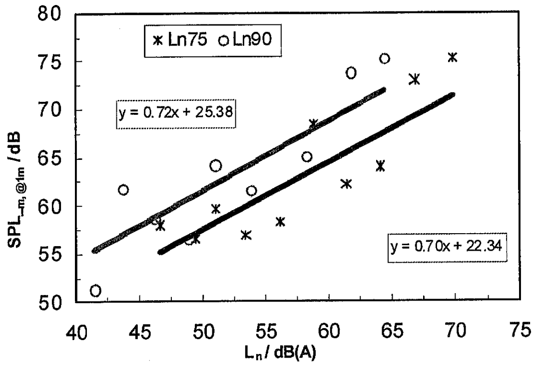


**Figure 2:** Relations between $L_{A75}$ and $L_{A90}$ and $SPL_{m,@1m}$ values during traditional lessons and best-fit regression lines. The $SPL_{m,@1m}$ values were averaged on an $L_n$ intervals of 2.5 dB.

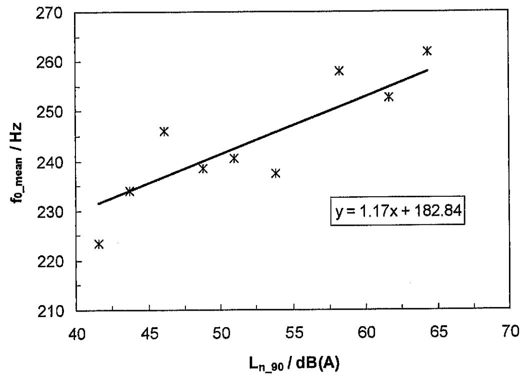


**Figure 3:** Relation between mid-frequency $L_{A90}$ and $f_{0,mean}$ values during traditional lessons and best-fit regression line for female subjects. The $f_{0,mean}$ values were averaged on an $L_{A90}$ intervals of 2.5 dB.

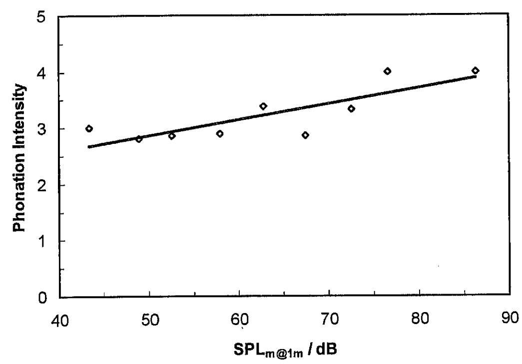


**Figure 4:** Average phonation intensity scores versus measured values of $SPL_{m,@1m}$ and best-fit regression line. The five-point scale is bounded by the words "very low" (1) and "very high" (5). The scores were averaged on an $SPL_{m,@1m}$ intervals of 5 dB.

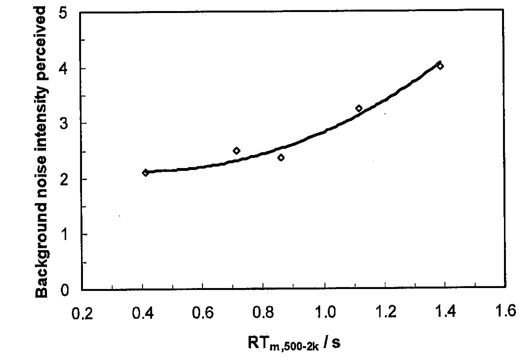


**Figure 5:** Average background noise intensity perceived scores versus measured values of $RT_{mean,500\text{-}2k}$ and best-fit regression line. The five-point scale is bounded by the words "very low" (1) and "very high" (5). The scores were averaged on an $RT_{mean,500\text{-}2k}$ intervals of 0.2 s.

## CONCLUSIONS

From the current data the following main conclusions can be drawn:

- Approximately 41 % of the examined subjects showed no sign of disease, while 59 % presented subjective and/or objectively measured pathological symptoms.
- The mean sound pressure level of the voiced speech at 1 m from the talker's mouth and the mean fundamental frequency during a full day teaching were re-

spectively 66.2 dB, U 2.08, and 238.7 Hz, U 4.46 for female, and 65.8 dB, U 2.68, and 150.3 Hz, U 9.62 for female.

- 'Students talking in the classroom' is judged to be the most annoying, intense and frequent noise source in classrooms.
- The most important consequences of the poor acoustics in all the schools were 'Loss of concentration' and 'Decrease in students question perception'.
- For the two groups of schools, Torino and Beinasco, the subjective assessments about teachers' vocal effort and background noise intensity are confirmed by the objective measurements of $SPL_{m,@1m}$, $L_{N\_ist}$ and $L_{A90}$.
- A Lombard effect corresponding to a 0.70-0.72 dB increase of speech level per 1 dB increase of noise level was found.
- The fundamental frequency increases with the increase in background noise at a rate of 1.4 Hz/dB.
- The "Perceived voice intensity" increases with the increase of $SPL_{m,@1m}$ and "background noise perceived intensity" increases with the square of the reverberation time.
- The main causes of a vocal pathology are $D_t$%, smoking and genetic predisposition, where $D_t$% represents both the vocal load in temporal terms and the speed of speech.

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