Proceedings of Meetings on Acoustics

Volume 11, 2010

<http://asa.aip.org>

**160th Meeting
Acoustical Society of America
Cancun, Mexico
15 - 19 November 2010
Session 5aSC: Speech Communication**

5aSC5. Influence of Classroom Acoustics on the Voice Levels of Teachers With and Without Voice Problems: A Field Study

David Pelegrin-Garcia*, Viveka Lyberg-Åhlander, Roland Rydell, Jonas Brunskog and Anders Lofqvist

***Corresponding author's address: Technical University of Denmark, Building 352, Ørstedes plads, Kongens Lyngby, DK-2800, Kongens Lyngby, Denmark, dpg@elektro.dtu.dk**

Many teachers suffer from voice problems and classroom acoustics has been considered as one of the potential hazards for this. The present study examines how classroom acoustics interacts with the voices of 14 teachers without voice problems and 13 teachers with voice problems. The assessment of the voice problems was made with a questionnaire and a laryngological examination. During teaching, the sound pressure level at the teacher's position was monitored. The teacher's voice level and the activity noise level were separated using mixed Gaussians. In addition, objective acoustic parameters of Reverberation Time and Voice Support were measured in the 30 empty classrooms of the study. An empirical model shows that the measured voice levels depended on the activity noise levels and the voice support. Teachers with and without voice problems were differently affected by the voice support of the classroom. The results thus suggest that teachers with voice problems are more aware of classroom acoustic conditions than their healthy colleagues and make use of the more supportive rooms to lower their voice levels. This behavior may result from an adaptation process of the teachers with voice problems to preserve their voices. [Work supported by AFA.]

Published by the Acoustical Society of America through the American Institute of Physics

INTRODUCTION

Voice is the primary working tool of teachers, and a good voice is essential for communicating with students. Nowadays, many teachers suffer from voice problems. A recent study reported that around 13% of the active school teachers in southern Sweden self-reported voice problems [1]. Voice health problems are a major concern, not only due to the required clinical assistance and the personal consequences in job dissatisfaction and lack of self-esteem, but also due to the financial impact that the teachers' absence produces in the global budget of the country [2]. Investigating possible causes for voice disorders from the testimonies of affected teachers, Vilkmán points out "bad classroom acoustics" as one of the hazards for voice health [3].

The present study analyzed the average voice levels used at work by teachers with and without voice problems as a function of relevant environmental acoustic parameters. Two acoustic parameters were considered important: the activity noise level, due to the presence of students and other noise sources during teaching, and the voice support offered by the classroom. Three steps were necessary in the study: first, the choice of teachers and the assessment of voice problems. Second, the monitoring of the teacher's voice levels and the activity noise levels during teaching, and last, the measurement of objective acoustic parameters in the empty classrooms.

METHOD

Choice of teachers

A total of 27 teachers in 5 different schools in the south of Sweden, at educational levels ranging from primary school to high school, were considered for this study. The participants were selected as a follow-up to an epidemiological study [1].

The teachers were classified into two groups: one group (test; $N_T = 13$, 2 male/11 female) containing the teachers with voice problems and another group (control, $N_C = 14$; 2 male/12 female) with those teachers having no remarkable voice problems. The assessment of voice problems was made by means of the VHI-T (Voice Handicap Index with Throat subscale) questionnaire [4] and a laryngological examination.

Measurements during teaching

The teachers were equipped with an IEC 61672-compliant, type 2, sound level meter SVANTEK SV-102. This device measured and stored the A-weighted sound pressure level (SPL), using an exponential averaging with "fast" time constant, sampled at 1 s intervals. The microphone capsule was attached to the teachers' clothing neck, as a lapel microphone, at a distance of about 15 cm from the mouth.

The sound level meter operated for one working day. For each teacher, two SPL sequences were studied. One of them corresponded to a lesson at the beginning of the day and another one to a lesson at the last hour. The duration of the lessons was between 30 and 45 minutes. An example sequence is shown in Fig. 1 and the corresponding histogram is shown as gray bars in Fig. 2.

In these SPL sequences, it was assumed that the SPL from the teacher's voice was several dB higher than the SPL from activity (originated from students, ventilation noise and other external sources), because of the closer placement of the microphone to the teacher's mouth (around 15 cm). The time fraction while the teacher was talking was noted as α . The activity levels were obtained while the teacher was silent, during a time fraction $1 - \alpha$.

The teacher's voice (S) and activity noise (N) levels were assumed to be random processes coming from normal distributions, with probability density functions $f_S(L)$ and $f_N(L)$, respectively, where L indicates the A-weighted SPL. The means of these distributions are notated $L_{50,S}$ and $L_{50,N}$ (the symbol L_{50} indicates the level that is exceeded during 50% of the time, also referred to as median level), and their standard deviations σ_S and σ_N . As an example, these distributions are indicated in Fig. 2 with dash-dot and dashed lines, respectively. Thus,

$$S \sim \mathcal{N}(L_{50,S}; \sigma_S) \rightarrow f_S(L), \quad (1)$$

$$N \sim \mathcal{N}(L_{50,N}; \sigma_N) \rightarrow f_N(L). \quad (2)$$

FIGURE 1. A-weighted SPL at the lapel microphone worn by the teacher during one lesson

FIGURE 2. In gray, histogram computed from the A-weighted SPL values in Fig. 1. On top, scaled normal probability density functions corresponding to the activity noise (dashed line), the teacher's voice (dash/dot line), and the addition of both processes (solid line).

The joint process corresponding to the observed A-weighted SPL values was regarded as having a probability density function $f_{S+N}(L)$, obtained by overlapping the two normal distributions $f_S(L)$ and $f_N(L)$, scaled by their probability of occurrence in time (α and $1 - \alpha$, respectively):

$$f_{S+N}(L) = \alpha f_S(L) + (1 - \alpha) f_N(L). \quad (3)$$

According to this principle, a linear combination of two normal distributions was fitted to the A-weighted SPL histogram, by minimizing the squared error with the simplex algorithm implemented in the function `fminsearch` of MATLAB. In this way, there were 5 estimated parameters ($L_{50,S}$, $L_{50,N}$, σ_S , σ_N , and α) for each sequence, although only the A-weighted median levels for the teacher's voice ($L_{50,S}$) and the activity noise ($L_{50,N}$) were used in the analysis. As an example, the probability density function fitted to the measured A-weighted SPL is shown with a solid line in Fig. 2. A similar approach to determine speech and noise levels in classrooms has been previously used [5].

Classroom acoustic measurements

Acoustic measurements were performed in the 30 classrooms where the teachers held their lessons, while they were empty.

Reverberation time. The reverberation time (RT) was calculated according to the standard ISO 3382-2 [6]. The sound source was a B&K Omnisource type 4295, placed at the teacher's position and with the radiating opening at a

FIGURE 3. Mid-frequency average reverberation time values measured in the classrooms

FIGURE 4. Setup used to measure the mouth-to-ears impulse response in the classrooms

height of 1.6 m. Two 1/2" pressure-field microphones B&K type 4192 were used as receivers and were placed close to students' seats at a height of 1.2 m. The 01dB Symphonie system, incorporating the MLS software module, was used to produce the measurement signal and send it to the loudspeaker via a power amplifier, acquire the signal from the microphones, calculate the impulse responses, and derive the RT_{20} . The measured RT values in the classrooms, corresponding to the average of the 500 Hz and 1 kHz octave frequency bands, are shown in Fig. 3. However, the RT was not used in the empirical model due to the lack of normality in the measured values. The three 'outliers' in reverberation time correspond to three sports hall that were used for gymnastics lessons.

Voice support. Instead, the focus in this research was on characterizing the acoustic conditions of classrooms as perceived by the teachers while talking. A parameter called *Voice Support* (ST_V) is introduced in this paper as a measure of how much the sound reflections at the room boundaries amplify the voice of the teacher at his/her ears (NOTE: The exact definition of ST_V is given below).

The voice support is calculated from an impulse response corresponding to the airborne sound transmission between the mouth and the ears (or simply, mouth-to-ears impulse response). For this purpose, a Head and Torso Simulator (HaTS) B&K type 4128 was used. The HaTS included a loudspeaker at its mouth, and microphones at its ears. The HaTS was placed at a representative teaching position, with the mouth at a height of 1.5 m. The 01dB Symphonie system was used to produce the excitation signal and determine the mouth-to-ears impulse response from the measured signal at the microphones. The setup used to measure the mouth-to-ears impulse response is shown in Fig. 4.

From the measured mouth-to-ears impulse response $h(t)$ (example shown in Fig. 5), the direct sound $h_d(t)$ is obtained by applying a window $w(t)$ to the measured impulse response $h(t)$,

$$h_d(t) = h(t) \times w(t), \quad (4)$$

FIGURE 5. Example of a measured mouth-to-ears impulse response, with the windowing applied in order to calculate the direct and the reflected airborne sound components of one's own voice.

where $w(t)$ is

$$w(t) = \begin{cases} 1 & t < 4.5 \text{ ms} \\ 0.5 + 0.5 \cos(2\pi(t - t_0)/T) & 4.5 \text{ ms} < t < 5.5 \text{ ms} \\ 0 & t > 5.5 \text{ ms} \end{cases} \quad (5)$$

with $t_0 = 4.5 \text{ ms}$ and $T = 2 \text{ ms}$. The reflected sound $h_r(t)$ is the complementary signal

$$h_r(t) = h(t) \times (1 - w(t)) = h(t) - h_d(t) \quad (6)$$

From the above signals, the energy levels corresponding to the direct sound ($L_{E,d}$) and the reflected sound ($L_{E,r}$) are calculated as

$$L_{E,d} = 10 \log \frac{\int_0^\infty h_d^2(t) dt}{E_0}, \quad (7)$$

$$L_{E,r} = 10 \log \frac{\int_0^\infty h_r^2(t) dt}{E_0}. \quad (8)$$

From these two equations, the *voice support* ST_V , in analogy to Gade's objective support [7], is defined as the difference between the reflected sound and the direct sound from the mouth-to-ears impulse response,

$$ST_V = L_{E,r} - L_{E,d}, \quad (9)$$

The ST_V values measured in the 30 classrooms of the study, averaged for two HaTS positions and the two ears, without applying any filtering, are shown in Fig. 6. The average value is indicated with a solid line, whereas one standard deviation above and below the mean is indicated with dashed lines.

Statistical method

We used a multiple regression to analyze the combined influence of the covariates *voice support* (ST_V) and *median activity noise* ($L_{50,N}$) on the teachers' median voice levels ($L_{50,S}$). The two covariates ST_V and $L_{50,N}$ were fairly uncorrelated ($\rho = -0.07$). Additionally, we accounted for possible differences in voice use between the teachers of the test and control groups (with and without voice problems) by including a binary variable named Test/Control which indicated which group the teacher belonged to.

Since we considered the effect of ST_V and $L_{50,N}$ to be potentially different for the teachers of the test and control groups, we included also the interaction between the Test/Control variable and the two covariates. Nevertheless, the

FIGURE 6. Voice support values measured in the 30 classrooms, by averaging the results of two positions and the two ears in each room.

interaction between $L_{50,N}$ and Test/Control was found to be non-significant ($F_{1,48} = 0.15, P = 0.70$) and was left out from the final model.

We fitted the model in R [8] using the function `lm`. Prior to running the model, we applied the square root, affine transformation to the activity noise levels $\sqrt{75 - L_{50,N}}$, in order to obtain an approximately normal distribution of the observed values of the covariate. None of the measured noise levels was higher than 75 dB.

This transformed variable, and ST_V , which already presented an absence of outliers and skew, were further z-transformed. We checked various diagnostics of model validity and stability (Cook's distance, dfits, distribution of residuals, residuals plotted against predicted values) and none of these indicated obvious influential cases or outliers, nor obvious deviations from the assumptions of normality and homogeneity of residuals [9]. The significance of each variable in the model was assessed by means of F-tests resulting from an analysis of variance.

RESULTS

Overall, the median voice levels were clearly influenced by the combination of predictor variables in the proposed statistical model ($R^2 = 0.69, F_{4,49} = 27.8, p < 0.001$):

$$L_{50,S}(\text{test}) = 81.3 - 3.87 \times \sqrt{75 - L_{50,N}} - 0.72 \times ST_V \text{ [dB]}, \quad (10a)$$

$$L_{50,S}(\text{control}) = 102.9 - 3.87 \times \sqrt{75 - L_{50,N}} + 0.84 \times ST_V \text{ [dB]}. \quad (10b)$$

The effect of the transformed noise levels on the voice levels ($F_{1,49} = 92.2, p < 0.001$) was highly significant. The overall effect of the covariate voice support ST_V ($F_{1,49} = 0.65, p = 0.43$) and the factor Test/Control ($F_{1,49} = 2.12, p = 0.15$) were not significant at the 5% level. However, the interaction between the ST_V and the Test/Control variable was found to be highly significant ($F_{1,49} = 16.5, p < 0.001$).

The measured $L_{50,S}$ values as a function of ST_V are shown in Fig. 7. For the average observed noise levels ($L_{50,N} = \bar{L}_{50,N}$), the model (10) is:

$$L_{50,S}(\text{test}) = 69.8 - 0.72 \times ST_V \text{ [dB]}, \quad (11a)$$

$$L_{50,S}(\text{control}) = 91.4 + 0.84 \times ST_V \text{ [dB]}. \quad (11b)$$

For teachers without voice problems (control group), the median voice levels increased with the measured voice support at a rate of 0.8 dB/dB. On the other hand, teachers with voice problems (test group) lowered their voice levels the higher the voice support, at a rate of -0.7 dB/dB.

FIGURE 7. Median voice SPL used by teachers versus voice support measured in the empty classrooms. The solid lines show the regression model in (11). The two teacher groups make use of the voice support in significantly different ways.

FIGURE 8. Median voice SPL used by teachers versus median activity noise SPL. The solid lines show the regression model (12). As a consequence of the Lombard effect, the voice levels increase with the noise levels, equally for teachers with and without voice problems. However, teachers in the control group use higher voice levels than those in the test group.

The measured $L_{50,S}$ values as a function of $L_{50,N}$ are shown in Fig. 8. For the average observed voice support ($ST_V = \overline{ST}_V$), the model (10) is:

$$L_{50,S}(\text{test}) = 90.6 - 3.87 \times \sqrt{75 - L_{50,N}} \text{ [dB]}, \quad (12a)$$

$$L_{50,S}(\text{control}) = 92.0 - 3.87 \times \sqrt{75 - L_{50,N}} \text{ [dB]}. \quad (12b)$$

For all teachers, There was an increase of median voice level with the activity noise present during teaching. This increase was non-linear in the observed range of levels, being more relevant for the highest noise levels. Additionally, the teachers from the test group talked 1.4 dB on average softer than the teachers in the control group. However, this difference was not statistically significant with the number of teachers considered in this study.

DISCUSSION

Teachers from the test group (with voice problems) decreased their voice levels with increasing voice support (-0.7 dB/dB) in the classrooms, as opposed to the control group (without voice problems, 0.8 dB/dB). The behavior of the test group would be desirable for the prevention of voice problems. The measurements suggest that teachers from the test group made good use of the voice support as an adaptive mechanism to preserve their vocal health. This finding supports the results from a study by Kob *et al.* [10], who found that teachers with voice problems were more affected by poor classroom acoustics than their healthy colleagues. The behavior of the teachers in the test group follows the results of Brunskog *et al.* [11], who found that teachers lowered their voice levels as a function of the amplification offered by the room to their own voice. However, the behavior of teachers in the control group does not follow a logical pattern. A hypothetical answer would be that the voice support increases in rooms with sound reflecting boundaries, and the activity noise levels would increase in this case. Due to the Lombard effect, the talkers (students and teacher) would perceive increased noise levels and automatically raise their voices. However, the lack of correlation between voice support and activity noise invalidates this hypothesis.

Teachers from the test and control groups were equally affected by noise. Both groups increased their vocal intensity with increasing activity noise, in accordance with the Lombard effect. If the curves are approximated by straight lines for $L_{50,N}$ above 55 dB, the slope is 0.6 dB/dB, in good agreement with the literature (for example, Lazarus reports slopes between 0.5 dB/dB and 0.7 dB/dB [12]). The teachers from the test group talked on average 1.4 dB softer than the control group, although this difference was not significant. Nevertheless, this might be an additional indication that teachers with voice problems tried to limit their vocal effort in terms of vocal intensity.

CONCLUSIONS

The main conclusions from the field study are the following:

- Teachers with voice problems make a more efficient use of the voice support in classrooms than their healthy colleagues, probably as an adaptive mechanism to preserve their voice health.
- Teachers with and without voice problems react identically to changes in activity noise, according to the Lombard effect.

ACKNOWLEDGMENTS

The authors wish to express their gratitude to all the teachers and staff of schools participating in the measurements. This research has been funded by the Swedish company AFA Försäkring as a part of the project "Speaker's comfort and voice health in classrooms".

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