Experimental investigations of the influence of room acoustics on the teacher’s voice

Malte Kob*, Gottfried Behler†, Anja Kamprolf‡, Oliver Goldschmidt§ and Christiane Neuschaefer-Rube¶

Department of Phoniatrics, Pedaudiology, and Communication Disorders, RWTH Aachen University, Pauwelsstr. 30, 52074 Aachen, Germany

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Abstract: Teachers belong to the group of professional voice users who often suffer from voice disorders. A reduction of the voice capacity can impede or stop the exertion of their profession. One reason for a significantly increased prevalence of voice problems can be poor room acoustical conditions in the class rooms. About the half of the teachers of a secondary modern school in Aachen were investigated with respect to their voice status by using phoniatic, logopedic and objective voice analysis methods. The prevalence of voice problems in this group was found to exceed previous studies where subjective voice quality was rated. Four rather reverberant and loud class rooms in that school were analysed using measurements of the reverberation time, $T_{30}$, and the speech transmission index, STI. In a further part of this joint project the change of voice quality during the teachers’ working day was analysed. Two of the four rooms were acoustically optimised. Members of two groups of teachers with and without voice problems were recorded before and after teaching in either one of the acoustically poor rooms or one of the newly renovated rooms. The results indicate statistically significant differences between the groups of subjects with respect to one or more voice parameters. Healthy subjects are less affected by unfavourable room acoustical conditions than subjects with voice problems.

Keywords: Voice disorders, Classroom acoustics, Voice quality assessment

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1. INTRODUCTION

Professional voice users such as singers, teachers or call center agents rely on the performance of their voice [1]. A reduction of the voice capacity can impede or stop the exertion of their profession. The acoustics of a room can restrict or support the singer or speaker and improve the sound of the voice and the intelligibility of speech. Previous studies found that teachers suffer more often from voice disorders than non-professional voice users [2,3]. Roy et al. [4] report a prevalence of voice disorders in teachers of 11% compared to 6% in non-teachers, assessed through a questionnaire.

The voice of teachers can be charged by disadvantageous acoustic conditions such as background noise inside and outside the class room. But also the room acoustics in the class room itself can reduce the voice intelligibility through reinforcement of the environmental noise and increased diffuse sound. A chronic increase of voice level due to a high background noise in the class room can be considered as a risk factor for the voice of teachers and can be a cause of dysphonic voice [5].

For several reasons, the room acoustical conditions in class rooms are often not well adopted to the teaching task: poor sound isolation to school yards, corridors and neighboured rooms can produce additional noise which adds to the sound produced by the pupils in the class room. Often, the floor is not sufficiently or not at all covered.

Some rooms show strong reverberance or even echoes which can make communication difficult. When the room acoustical support is rather weak, the voice performance can be strongly reduced, and more effort of the teacher is necessary to convey the speech to the listeners. The problem for the pupils is a reduced intelligibility of the teacher’s speech [6] which often causes a lack of attention.
and concentration resulting in worsening of the learning conditions [7].

In an earlier study, we tried to find a direct influence of the reverberance of a virtual acoustic environment on the voice quality of a speaker under test during reading of a text [8]. However, in the two healthy subject under test no significant influence of the reverberation time on the voice quality was observed.

For the teacher, in a long term, this additional voice load can result in voice disorders such as hoarseness, voice fatigue [9] and even force teachers to retire early from their profession. Female teachers have a higher probability of voice disorders than males. Among the symptoms scratchiness and tiredness were the most frequent disorders among woman compared to scratchiness in males [10].

Previous studies have investigated the voice change in female secondary school teachers during a working day [11]. In this study an increase of the fundamental frequency was observed. In other studies of that research group the working-day effect on the voice spectrum [12] and the relationship between subjective and acoustic voice parameters [13] were investigated.

These findings motivated us to investigate the relation between room acoustical conditions and voice parameters of teachers in a secondary modern school in Aachen. Our pilot study tries to find out whether disadvantageous acoustics in class rooms contributes to voice problems in teachers.

2. METHOD AND RESULTS

2.1. Subjects

All 50 teachers of the secondary modern school were asked to participate in the study. From these, 25 (19 female, 6 male) agreed to participate. No selection according to voice status was made. The average age of the teachers was 47.5 years (median: 47) and the age ranged from 32 to 62 years.

2.2. Voice Status of Teachers

In the first part of the project the volunteering teachers were initially investigated in the Department of Phoniatrics, Pedaudiology, and Communication Disorders of RWTH Aachen University in the period 12/2004–1/2006. A sequence of phoniatric, audiometric, logopedic and acoustic voice investigations were carried out. From each subject a questionnaire was completed which asked for preferred or problematic rooms in the school, comments on the room acoustical conditions during teaching and the subjective voice status.

As a result of the investigations a classification of the subjects with respect to voice pathology was made in the categories “noticeable findings” when a therapy was strongly recommended, “minor findings” when a therapy was advisable, or “no findings” when the subject was healthy according to the investigation.

2.2.1. Phoniatrics

The medical investigation consisted of an anamnesis interview, visual inspection of mouth, ear, nose, pharynx and larynx and videostroboscopy (phase difference, amplitude of vibrations, variability of mucosal wave). The classification of the health status demonstrated in Fig. 1 was mainly based upon the stroboscopic findings.

2.2.2. Audiometry

The audiometric investigation comprised of a tympanogram and a pure tone audiogram.

2.2.3. Logopedics

The perceptive logopedic investigation was carried out by a speech therapist. The general impression, tonus and communication abilities were observed. The respiration was assessed by measurement of the expiration duration and maximum phonation time. Speech was evaluated perceptually with respect to voice quality, voice on- and offset, voice intensity and speech rate.

For the group of teachers in the range of age 45-62 years a significantly higher occurrence of disordered voice was observed when comparing to to the range of 32-44 years ($p = 0.013$, age grouping according to e.g. Coyle et al. [14]).

2.2.4. Voice acoustics

The acoustic voice assessment was carried out by a speech therapist in an anechoic room. A voice range profile was recorded according to the recommendations of the Union of the European Phoniatricians [15] using the system “phoneto” [16]. Voice signal analysis was performed using the system OVALA (On-line Voice Analysis Laboratory Aachen, [17]). The system offers a hoarseness analysis with the Göttingen Hoarseness Diagram [18]. The teachers read the German text “Nordwind und Sonne,” and recordings of sustained vowels were made (/a/, /e/, /i/, /o/ and /u/). The vowels were recorded three times each.

In Fig. 1 the results from the investigations of the teachers are depicted, classified according to the method of investigation and sub-classified according to the result of the investigation of the voice status. In the case of the phoniatric investigation only a binary decision was made. The voiced was classified “disordered” when the stroboscopy or visual inspection of the larynx exhibited a noticeable pathologic finding which requires a treatment. The other investigations were classified in three categories.

From these investigations it was found that a higher percentage of the teachers show voice problems in comparison to previous investigations of the prevalence of voice disorders in non-professional voice users which were based upon an interview [4,19].
2.3. Room Acoustics of Class Rooms

Teachers as well as pupils of a secondary modern school in Aachen, Germany, suffered from unfavourable room acoustical conditions in most of their class rooms. This mainly was reflected in a rather long reverberation time and due to this in moderate STI-values that are closely related to speech intelligibility (Fig. 2). The STI shown here was calculated from noiseless room impulse response measurements according to IEC 60268. Considering background noise and occupancy with 20 people in the classroom would significantly reduce the STI values.

The general situation of the modern part of the school building — erected in the late seventies — was a major concern of most of the teachers and they complained mostly about noisiness and problems with their own speech. At the time they contacted the Institute of Technical Acoustics at RWTH Aachen University they already were in contact with companies producing acoustic ceilings and carpets. However, professional support was required, first for the documentation of the present acoustical situation and, furthermore, for the design of the acoustical treatment for a pilot study that could be used to convince decision-makers in the school administration to spend the required amount of money for the entire building.

When visiting the school building a number of four similar rooms could be addressed that were situated side by side at one floor and therefore most usable to make comprehensive investigations with different treatments. Due to the fact that each two of the four rooms were rather identical it was decided to treat one of each rooms to yield improved acoustics and to leave the other one in the original configuration. Hereby, the possibility to change classrooms for one group of pupils and their teacher was given and therefore the precondition to perform comprehensive studies was met.

As it can be seen easily from Fig. 2, the reverberation times are far too long for a classroom. As indicated in DIN 18041 a reverberation time of about 0.6 seconds would be
desirable. As a consequence, the speech transmission indices are at best acceptable. With respect to the available materials (ceiling absorbers) and the increase of the reverberation at low frequencies a combination of a highly absorbent porous material at the edges of the ceiling in combination with a low frequency absorber (non-porous) in the centre part of the ceiling was chosen. By this means the reflectivity of high frequencies and hence an improvement of loudness for the direct sound was aimed.

The calculation of the reverberation times was made with quite conservative methods by using Sabine’s formula. In Figs. 3 and 4 the results for the prediction in comparison with the final measurements in the class rooms are depicted.

In both class rooms the final reverberation time for the unoccupied case was below 0.6–0.5 seconds. The reverberation times in the occupied rooms (about 0.4 seconds) did not vary much from the unoccupied state which in any case is a favourable situation since it provides good acoustical conditions for varying occupancy. The speech intelligibility indices have been improved to 0.72–0.76, which can be considered relatively good.

In addition with the ceiling treatment the two class rooms were furnished with needle felt carpets. Even though this may be marginal for the reverberation it is quite important with respect to major noise sources found in class rooms, namely the scrabble of feet, the sliding of chairs, and the dropping of items.
2.4. Experiments during Teaching

The subjects who participated in this part of the investigation were selected according to the following categorisation (see Table 1).

The reduction of the total number of available teachers for this investigation was reduced due to the fact that some did not comply with the requirements of the investigation due to their voice status \( (n = 6) \). Another part of the group could not participate for other reasons \( (n = 5) \). A few comparisons \( (n = 3) \) could not be completely evaluated.

In the last part of the study, we tried to find an influence of the voice load during teaching sessions on selected properties of the teachers’ voice. Four different sets of measurements were performed on each of fourteen subjects: before and after 1–4 hours of teaching in the unchanged, rather reverberant, room and in the acoustically optimised room. Acoustic analyses were obtained from recordings just before and after teaching in a library with dry acoustics \( (T_{30} < 0.5\,\text{s}) \) using an AKG microphone and a microphone pre-amplifier. The signal was digitized with a standard sound card. The sound files were recorded, processed and evaluated with the OVALA system [17].

Statistical analyses were carried out using SPSS-15 software. A three-factorial repeated measures ANOVA with the two repeated measures factors teaching (before, after) and room (unchanged, acoustically optimized) and the grouping factor voice findings (no, minor, noticeable) was used to study their impact on 5 different voice parameters (voice pitch, voice level and voice quality of vowels; voice pitch, and voice level of reading text). Since this study was considered to be a pilot investigation no correction for multiple testing concerning the voice parameters was carried out and for each ANOVA a type-I error level of 10% was chosen.

In the following sections selected results are reported.

Voice pitch of vowels: The voice pitch of each sustained vowel was analysed using the AMDF algorithm. Mean and standard deviation, median, maximum and minimum pitch frequency were calculated.

For the group of all subjects the results indicate a statistically significant lower mean pitch after teaching in the optimised rooms whereas the mean pitch was not as strongly reduced after teaching in the acoustically unfavourable rooms \( (p = 0.094) \).

After teaching in the optimised rooms the pitch standard deviation decreases, whereas after teaching in the acoustically unfavourable rooms the pitch standard deviation increases \( (p = 0.049) \). Figure 5 shows this result.

Voice pitch of reading text: The voice pitch of the text “Nordwind und Sonne” was also analysed using the AMDF algorithm.

For all groups, the evaluation of the standard deviation of the voice pitch showed a moderate increase of the standard deviation after teaching in the room with good acoustical conditions and decreases after teaching under bad acoustical conditions \( (p = 0.083) \).

Voice level of vowels: The evaluation of the vowel recordings are shown in Fig. 6. The results indicate that the healthy teachers show small variations of sound pressure level disregard the time or place of teaching. The other two groups show a bigger variance in sound pressure level. However, these results are not statistically significant \( (p = 0.120) \).

Voice level of reading text: Under good room acoustical conditions the sound pressure level did not change or decrease slightly in all groups of teachers. In unfavourable conditions, the sound pressure level of the teacher’s voice increases for the non-healthy groups and did not change in the group of healthy teachers. These results are not statistically significant \( (p = 0.127) \).

Voice quality: The analysis of voice quality with respect to irregularity exhibits a statistically significant influence of the room type \( (p = 0.028) \). The mean value decreases after teaching under good room acoustical conditions whereas

<table>
<thead>
<tr>
<th>Category</th>
<th>Voice status</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>No findings</td>
<td>Healthy with respect to phoniatrics and logopedics</td>
<td>3/1</td>
</tr>
<tr>
<td>Minor findings</td>
<td>Healthy according to phoniatrics, voice training recommended</td>
<td>2/1</td>
</tr>
<tr>
<td>Noticable findings</td>
<td>Healthy according to phoniatrics, perceptually disordered voice</td>
<td>3/1</td>
</tr>
</tbody>
</table>

Table 1 Categorisation of teachers in three subgroups of \( n \) female/male subjects.

Fig. 5 Comparison of voice pitch standard deviation of all teachers before and after teaching in different rooms.
the mean value increases under unfavourable conditions (see Fig. 7).

In Fig. 8, the voice signal analysis with respect to the ‘glottal noise to excitation ratio’ (GNE) [20,21] is shown for all groups before and after teaching in different rooms. The GNE standard deviation value is lower for the healthy group compared to the other two groups. In the healthy group, the values do not differ between rooms and before/after teaching. In the group with minor pathological findings the values tend to increase after teaching. In the group with noticeable pathological findings the noise variability decreases under good acoustical conditions whereas it increases after teaching in unfavourable room acoustics. These results are statistically significant (p = 0.003).

3. DISCUSSION

The differences in room acoustical conditions between the untreated and optimised class rooms represent different conditions for teaching. The optimised rooms exhibit a much more quiet atmosphere, and the subjectively assessed background level in these rooms is lower than in the acoustically unfavourable rooms. The change of room acoustical parameters before and after modification prove the effectiveness of the optimisation. The success of the acoustic treatment could be predicted through room acoustical calculations. However, the difference of the prediction accuracy at lowest frequencies between the Figs. 3 and 4 cannot be explained easily. A reason could either be a rather high uncertainty of the measurements, or the room 2 could in fact not be as well adjusted in reality as predicted by the simulation. The difference could also be caused by inaccurate assumptions of the material properties or ineffective placement of the absorbing material in the second room.

All teachers teaching in the optimised rooms reported significant improvement of the acoustical conditions. Especially the carpet was reported to be a great improvement and the initial concern with respect to cleaning problems was minimized. As a consequence of the pilot study the school administration recently agreed to the complete renovation of the school building which can be seen as a great success of the project.

![Fig. 6](image1.png)

**Fig. 6** Comparison of mean sound pressure level for the three groups of teachers and different vowels.

![Fig. 7](image2.png)

**Fig. 7** Comparison of irregularity values before and after teaching in different rooms.

![Fig. 8](image3.png)

**Fig. 8** Comparison of GNE standard deviation values for different groups before and after teaching in different rooms.
The availability of both types of rooms in one school is a valuable tool for comparison tests of teaching conditions. However, the control of the environmental conditions including background noise and actual sound absorption in the room is difficult, because the behaviour of the pupils, their number and a potential influence of clothing (winter/summer or light/stormproof) has not been controlled in our study. Teachers and pupils are aware of the different conditions in the rooms and might consciously change their behaviour in each type of room.

The recording of the teacher’s voice and the background noise level during teaching would give valuable information about voice load and acoustic teaching environment. In our study such an investigation was not feasible due to the short investigation periods (1 to max. 4 hours). The attentiveness of pupils during some preliminary in-situ measurements in the class rooms was rather strongly affected. The reason was the need to prepare the teacher with the mobile recording device (microphone + DAT recorder) and to set up the microphone and laptop for the room acoustical measurements. This effect would probably be less strong when longer teaching sessions are investigated. In addition, more subtle recording methods such as dosimetry of the voice using contact microphones and hidden recording devices should be used in future investigations.

The phoniatric, audiometric and logopedic voice status assessment of teachers from a secondary modern school in Aachen lead to detailed conclusions. The clinical assessment was mainly based on visual vocal fold function using stroboscopy. From this inspection one fifth of the teachers were classified in the group with noticeable pathologic findings. The logopedic methods seem to generally yield a higher percentage of non-healthy subjects, only about 30% of the teachers are classified in the healthy group. These differences can be explained by the nature of the voice problems. The majority of voice problems in this group of teachers does not seem to be caused by severe vocal fold dysfunction but rather by problems with the voice performance and voice quality. This assumption is confirmed by the results from the voice range profile analysis and the hoarseness diagram evaluation. However, it must be noted that the 25 teachers could not be representative for the whole teaching staff of the school.

The comparison of the voice status before and after some hours of teaching has required a multidimensional statistic evaluation of various voice parameters. The parameter changes are never very strong, and the test of statistical significance is difficult with the rather small number of eleven subjects who participated in this test (n = 3 to n = 4 in each sub-group, see section 2.4). Statements regarding age- or gender-related effects ([1,10,11]) were not made due to the small number of subjects. However, some conclusions can be drawn from these evaluations.

The voice pitch is a sensitive indicator for voice load [22,23]. A correlation of voice pitch (mean and standard deviation) of vowels with voice loading in different rooms could be observed in our study: in acoustically better rooms the mean voice pitch before/after teaching decreased stronger than in unfavourable rooms. The standard deviation decreases after teaching under good acoustical conditions, and increases slightly after teaching under bad acoustical conditions. The voice signal seems to represent less vocal loading and smaller variations in sustained sounds. The voice pitch of reading texts give a different view on the voice: the loading by teaching in acoustically bad conditions seems to reduce the variability of the teacher’s fundamental frequency which could indicate a more monotonic voice. Under good conditions, the variability increases, which could represent a more prosodic voice.

The evaluation of the voice level does not give statistically significant results with respect to the choice of rooms. However, the results indicate that the voice level of healthy teachers seems to be more constant than the voice level of the other two groups. A slight increase of SPL could be observed for the non-healthy groups after teaching in favourable acoustical conditions. A decrease was observed in non-healthy teachers after teaching in good acoustical conditions which is in agreement with other studies. Some studies found a lowered SPL in teachers with less vocal loading (e.g. [22,24]), but these studies investigated the influence of sound amplification during a longer teaching period.

The evaluation of voice quality indicates an improved voice irregularity after teaching in good room acoustical conditions and an increased irregularity under bad conditions. Irregularity seems to be a sensitive indicator of voice quality [21]. This result are similar to the results of the study of Jónsdottir [24] who reported better voice quality in teachers with vocal loading when using electric sound amplification.

4. CONCLUSIONS AND FUTURE WORK

The relation of room acoustics to voice problems of teachers in a secondary modern school in Aachen, Germany, has been investigated in this study using an interdisciplinary collection of methods. With this project we hope to contribute to a better understanding of the relation between room acoustics and the teacher’s voice in class rooms. The conditions for this group of professional voice users could be improved by optimisation of the class room acoustics.

Our results agree with the well-known fact that the prevalence of voice disorders in teachers is increased.
compared to non-professional voice users. It was demonstrated that class rooms with rather unfavourable room acoustics can be modified in such a way that the key parameters for improvement of communication are optimized. Further results indicate that teachers with different voice status seem to tolerate voice load during teaching differently. Differences in the room acoustical conditions in classrooms seem to affect teachers with voice problems more than healthy teachers. However, bigger groups of teachers need to be investigated to obtain significant results. It would also be beneficial to investigate the effect of longer teaching sessions on the voice changes.

It was also found that voice analysis methods need to be further developed to improve their expressiveness and comparability among different research groups. Such activities are among the goals of the European COST Action 2103 “Advanced voice function assessment,” an interdisciplinary expert group of medical doctors and engineers. Future investigations should take into account the conditions of the teachers during the lessons. New assessment methods should enable the recording of environmental noise, voice load and stress-related factors such as heart-beat rate.

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Malte Kob received his doctoral degree in engineering sciences from RWTH Aachen University, Germany, in 2002. Since 2001, he is head of the section “Voice and Hearing Acoustics” of the Department of Phoniatrics, Pedaudiology, and Communication Disorders at the University Hospital Aachen, Faculty of Medicine of RWTH Aachen University. He is a member of ASA and DEGA.

Gottfried Behler received his doctoral degree in engineering sciences from RWTH Aachen University, Germany, in 1988. Since 1992 he works in the Department of Technical Acoustics, RWTH Aachen University. He is a member of AES, ASA and DEGA.

Anja Kamprolf studied logopedics at the Hogeschool Zuyd in Heerlen, The Netherlands and received her Bachelor of Health in 2006 with her thesis ‘Prevalence of voice disorders in teachers of a secondary modern school in Aachen.’ She is a postgraduate student at RWTH Aachen University.

Oliver Goldschmidt received his MD degree in 1997 from RWTH Aachen University. He worked in the Department of Phoniatrics, Pedaudiology, and Communication Disorders 2002–2006. He specialized in Oto-Rhino-Laryngology and Phoniatrics and Pedaudiology.

Christiane Neuschaefer-Rube received her MD degree from Friedrich-Wilhelm University, Bonn in 1987. Habilitation at the Medical Faculty of RWTH Aachen University in 2000. She is head of the Department of Phoniatrics, Pedaudiology, and Communication Disorders since 2001. She specialized in Oto-Rhino-Laryngology and Phoniatrics and Pedaudiology.