Acoustics'08 Paris
June 29-July 4, 2008
www.acoustics08-paris.org

Speaker comfort and increase of voice level in lecture rooms

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Teachers often suffer from health problems related to their voice. These problems are related to their working environment, including the acoustics of the lecture rooms. However, there is a lack of studies linking the room acoustic parameters to the voice produced by the speaker. The main goals in the present paper are to investigate whether objectively measurable parameters of the rooms can be related to an increase of the voice sound power produced by speakers and to the speaker's subjective judgments about the rooms. In six different rooms with different size, reverberation time and other physical attributes, the sound power level produced by six speakers were measured. Objective room acoustic parameters were measured in the same rooms, including reverberation time and room gain, and questionnaires were handled out to persons who had experience talking in the rooms. It is found that in different rooms significant changes in the sound power produced by the speaker can be found. It is also found that these changes mainly have to do with the size of the room and to the gain produced by the room. To describe this quality, a new room acoustic quantity called 'room gain' is proposed.

1 Introduction

The primary means of communication in most educational settings are speech and listening. The acoustics of the lecture room can support the speaker by improving the level and the intelligibility of speech – or the opposite. The room acoustics in lecture rooms is therefore an important issue when considering the productivity and working environment in schools and other teaching situations. Thus, a large amount of work has been carried out within this field. However, the large body of published articles focuses on the point of view of the listener. It is therefore easy to find works on speech intelligibility in rooms and advisable reverberation times and background noise levels in order to achieve good learning condition, et cetera, see e.g. Bistafa and Bradley [1]. There are also standards and recommendations [2, 3, 4], indicating how well established this field is. However, it is known that teachers often suffer from health problems or tension related to their voice. Recent works made it evident that teacher's labour is one of the professions with high vocal demands [5]. Examples of other professions with high vocal demands are actors, singers, journalists, telephone operators and military personal. Studies show that a majority of teachers have experienced vocal problems, about one tenth have severe problems, and 5\% have experienced such severe, numerous and frequent voice problems that their working ability is challenged [5]. For the teacher, in the long run, this voice load due to speaking in the classroom can result in voice disorders such as hoarseness, voice fatigue and can even force teachers to retire early from their profession. Lubman [6] discloses that this is an important economic problem for governments and private schools.

Most teachers have probably experienced that different rooms vary in comfort when one speaks in them. However, even though the vocal problem is so important, just a few studies about the speaker and his behavior in and impression of the lecture room have been accomplished. One example is Kleiner and Berntson [7], where the early reflections of the sound produced by the speaker were studied in a synthetic experimental setup. A system of loudspeakers in an anechoic chamber was used to simulate different rooms. All settings simulated rooms with different shape but the same volume. The interest was in the effect of lateral and vertical early reflections on the speakers' comfort. Different combinations of delayed simulated reflections were tested. A paired comparison test was used in order to find the setting preferred by the speakers. It was concluded that symmetrical settings were preferred over asymmetrical. There were however no significant difference between the different symmetrical settings, and perfectly symmetrical settings are not realistic in real rooms with a movable speaker. It can be noted that this was an entirely subjective study – no objective values were calculated from the simulated impulse responses. Kob et al. [8] has presented some preliminary results from a study where the voice status of 25 teachers were investigated using standard methods as applied by audimetrisists, phoniatricians and speech therapists, in addition to an acoustic analysis of speech and voice samples. The acoustics of some rooms was also investigated, but the study focused on reverberation time and speech transmission index. Thus, no clear distinction between the problem of the listener and the speaker were made.

Several studies in which different voice parameters were measured in real classrooms have been reported, e.g. Rantala et al. [9, 10] or Jonsdottir et al. [11]. However, in these studies the influence of the room was not included. Instead, the focus here was to study different subgroups of speakers, e.g. with and without voice problems. The voice parameters were primarily the voice level (defined as the sound pressure level (SPL) a distance of 1 m from the speaker) and pitch (more specific the fundamental frequency F_0 of the voice signal), and fluctuations in these parameters.

Thus, the literature relating the room with the speaker and the voice signal produced is rather thin; not much information is available on how to design or improve the room in order to make a better environment for the speaker. However, such information is available in the field of acoustics of rooms for music performance. Also here, the majority of works deal with the conditions for the audience, but there have also been studies concerning how musicians experience and react on the room acoustics. Important examples is Gade [12], who in a laboratory experiment in an anechoic chamber equipped with a loudspeaker system similar to Kleiner and Berntson [7] let musicians play in and react to simulated sound fields. Gade [13] also carried out corresponding subjective and objective studies in real concert halls. In both cases the subjective response answered by the musicians were correlated with different objective measures. Gade found that the 'support' provided by the room – the sensation that the room responds to his instrumental effort – is important for the musicians. Gade defines an objective measure, called ST, which correlates well with the sensation of 'support'. ST is determined as

$$ST=10 \log E_{20-x}/E_{dir} \quad (1)$$

where $E_{20\text{-}x}$ is the energy in the impulse response from 20 ms to x ms (x being either 100 ms, 200 ms, or even infinity), and E_{dir} is the energy in the direct path, defined as $E_{dir}=E_{0\text{-}10}$, that is the energy within the first 10 ms. The impulse response is to be measured with a source-receiver distance of 1 m. Obviously, 1 m distance is larger than the typical distance between the musicians ear and his instrument, but this distance was still chosen to obtain a measure with sensible variation and dynamic range. ST is thus the fraction of energy coming later than 20 ms relative the direct sound. In absence of reflected sound ST equals -∞ dB, and a zero support, ST=0 dB, means that the total contribution from the reflections equals the direct sound. This definition works well in large rooms where the direct part of the impulse response is clearly separated from the reflexions, but measurements of ST is problematic for smaller rooms. Another problem with the definition of ST is that it does not clearly reflect what happens close to the source, which at the same time is the position to be studied. In the real situation, e.g. in case of singing or speaking, the source is the mouth and the receiver position is the ear, just a few centimetres away. The direct path is thus described by the transfer function (or impulse response) from the mouth, around the head, to the ear in absence of reflections. How to deal with this is not obvious in case of the definition of ST. A third problem is that an anechoic chamber is included in the present study, and ST is undefined in such a room. Thus, in the present study we have made use of another definition, using the measured impulse response of a setup with an artificial dummy head torso, and taking as reference the measured value in an anechoic room. The new quantity is called room gain, abbreviation RG and variable G_{RG}.

It seems likely that the vocal problems of teachers are due to the voice level being increased in different situations where they feel the environment uncomfortable. Here the "environment" not only includes the physical environment of the lecture room, but also the behaviour of the students and the overall working conditions. There are two hypotheses here, one being that vocal health problems are related to an environment where the speaker feels that he must increase his voice, the other being that the physical environment it self can cause the speaker to increase his voice. Only the latter will be tested in the present paper. The aim of this project was thus to find some of the parameters that cause speakers to force their voices, and situations when it is uncomfortable to speak.

2 Method

Both subjective responses and objective measures of the room and of the voice level were collected. A selection of different natural acoustic environments were used – opposite of using a synthetic sound field. In simulated sound fields the variables can be changed rapidly and with precision within wide ranges. However, the sound quality is still limited due to the need of real time processing of the signals produced by the speaker. Moreover, the visual impression of the room can not easily be included -- this might be a positive aspect in many cases, but here it is important to get the visual size of the room and the distance to the audience right. Therefore, real rooms were chosen to be used -- six in total. The range in the physical parameters of the rooms used were wide, including small meeting and listening rooms; a medium size lecture room; two lager auditoria's, one with high reverberation time and one with low; and a large anechoic room.

In the six rooms the sound power level produced by six speakers were measured. Each of the speakers held a short lecture (about 5 minutes). Objective room acoustic parameters where measured in the rooms as well, and a subjective questionnaire was handed out to about 20 persons who had experience in speaking in the rooms. A statistical analysis was then used to find relationships between the subjective responses and the objective measures.

In the objective study 6 speakers were used. Three of these where teachers at Acoustic Technology, Elektro DTU, the other 3 were students in acoustics. Each speaker was instructed to give the same lecture in all rooms. However, as the speakers did not have a written text to read, the lectures were not identical. Most speakers used a laptop computer with a power point presentation as the basis of the speech. In order to get the background level identical, a laptop and a video projector (if available in the room) were present also for those not using it. In the subjective study 21 subjects participated (between 14 and 21 responses were collected for each room. The subjects were teachers and students in acoustics – the participants in the objective part were also present in the subjective part.

Objective measurements where preformed in the rooms, resulting in values of Early Decay Time, EDT, background noise level, $L_{BN,A}$, and the new parameter room gain G_{RG}, defined as the energy in dB in the signal relative to the direct energy as measured in the anechoic chamber,

$$G_{RG}=L_E-L_{E,ach}=10\log E/E_{ach}, \qquad (2)$$

where $L_{E,ach}$ and E_{ach} are the impulse energy level and the energy in the anechoic chamber respectively. Also the volume of the room was registered

With the rooms defined, the last step is to define the behaviour of the speaker in the room. In this project, this was described by the strength of the speaker's voice. The quantity used here was the *voice power level* VPL (variable L_W). Thus, the sound power level produced during speech by the different test speakers was measured in the different rooms. The measurement of the voice power level is a central issue of this paper. The measurements were made with a computer phone conversation headset, placed on the speaking subjects. A calibration procedure was needed to transfer the measured signals to sound power level L_W. The dummy head torso equipped with a loudspeaker in the mouth where placed in a reverberation chamber with the headset attached in the same position as described above. A broad band noise signal was fed to the loudspeaker and measured simultaneously by the headset and with microphones in the reverberant field of the room according to SWL standard measurements. Finally, having determined both L_W and L_p at the same time in the reverberation chamber, a gain constant was determined.

To get good statistic results, it is important to apply a wide range and even distribution of the different physical variables defining the room. The rooms and the values of the objective measures are given in Table 1. The rooms were: a small meeting room (MR) and an IEC listening rooms (IEC); a medium size lecture room (LR); two larger auditoria's, one with high reverberation time (A21) and one with low (A81); and a large anechoic room (ACH). Including the anechoic room means that the subjects have a very clear reference for reverberation time and room gain -- which both are zero in this room. Besides, ACH is relevant as it represents out door surroundings. The range covered by the volume, the reverberation time and the room gain can be considered as large in comparison to what can be found in real life situations. For the background noise, only the naturally present background noise was included. Thus, this variation is small as compared to what can be found in real life situations.

In an attempt to relate the objective parameters of the room and the voice power level to the subjective experience of the rooms a questionnaire was designed. The questions where formulated after a first interview with a few teachers. The parameters considered were: Regarding the overall impression of the room: – Is the classroom good to speak in? – Is it necessary to increase the voice? Regarding the physical aspects of the rooms: – Is there too much reverberation time? – Are there noticeable echoes? – Is the background noise too high? – Is there enough support in the classroom?

In more detail, the questionnaire's questions were the following (the actual questions are quoted in italic – and it should be noted that the English was not perfect!):

In which level you consider this room is good to speak in? This question is referring to the comfort and how easy it is to speak in the room. The rank was between "low", if they felt that the room was not good to speak in or "high" if they found the classroom was good to speak in. This parameter is labelled GSI, variable S_{GSI} . A high score is considered good.

Do you think the reverberation time is too long? This question clearly refers to the objective parameter of reverberation time. The rank in this case goes from "no" if they felt the reverberation was not too long or "yes" if they felt that it was too long. This parameter is labelled TR, variable S_{TR}. A low score is considered not too long.

In which level do you notice echo? The sensation of echo might influence the general impression of the room, so this response was introduced even though it is not represented in the objective parameters. The answers should be covered between "low", if they don't notice any echo in the room or "high" if the echo was too much. This parameter is labelled ECHO, variable S_{ECHO}. A low score is considered good.

The background noise is too much? People's responses could be between "yes", if they thought there was a lot of background noise in the studied room or no, if they thought that there was no noise in the room. This parameter is labelled BN, variable S_{BN}. A low score is considered good.

Do you have to increase your voice in this room to surely be heard? This question was related to the sound power level. The answers rate between "no", if people considered that they did not have to increase the voice to be heard or "yes", if they considered that they had to increase their voice a lot. This parameter is labelled IV, variable S_{IV}. A low score is considered good.

Could you evaluate if there is enough support in this classroom? This related to how the room helped the speaker feel that he could be heard by the listener. The rank is between "bad support", if they believed that the room did not yield support at all and "good support" if they found it to be sufficient. This parameter is labelled ES, variable SES. A high score is considered good.

The statistical analysis of the data was carried out in Matlab. The analysis incorporated ANOVA, correlation coefficients and linear regressions.

Name	-	V m^3	T_{EDT} s	G_{RG} dB	L_{BN} dB	nr	ΔL_W dB
Auditorium 81	A81	1900	1.12	0.28	41.8	14	-1.30
Auditorium 21	A21	1220	1.72	0.29	53.5	19	-0.08
Lecture r. 019	LR	190	0.40	0.42	47.5	21	-1.94
Meeting r. 112	MR	94	0.33	0.58	47.5	17	-4.33
Large anechoic ch.	ACH	1000	0.01	0	45.9	17	0
IEC listening r.	IEC	100	0.32	1.12	46.7	16	-4.32

Tabel 1 The rooms used in the experiments and there objective values. Nr means number of answers in the subjective questionnaire for each room.

3 Results

An analysis of variance (ANOVA) was used to examine if the variations in the data were significant. The variations were significant except for background noise BN, where no significant variations are found at the 5% level or better (p-value 0.16), and for detection of echo ECHO, where the variations are significant at the lower level of 5% (p-value 0.046), but not higher. It should here be noted that the variation in the background level of the rooms were small, and that there are no known problems with echo or flutter echo in any of the rooms used. In the same way, significance tests on different versions of the voice power level were performed. Here the significance of the variations in the data is less, probably due to the lower number of subjects participating.

However, taking VPL relative to the result in the anechoic chamber, ΔL_W, yields significant variations at the 5% level (p-value 0.036).

The objective parameters used to describe the rooms were presented in Table 1. The objective differences in the voice power level (ΔL_W) are also presented in Table 1. The mutual correlations between these parameters were then calculated, and it was noted that the VPL measures correlate well with the volume, especially log V, and the room gain GRG. There is no significant correlation between the VPL measures and reverberation time and background noise. It was also noted that the reverberation time measures do not correlate significant with any other measure, and the same thing holds for the background noise.

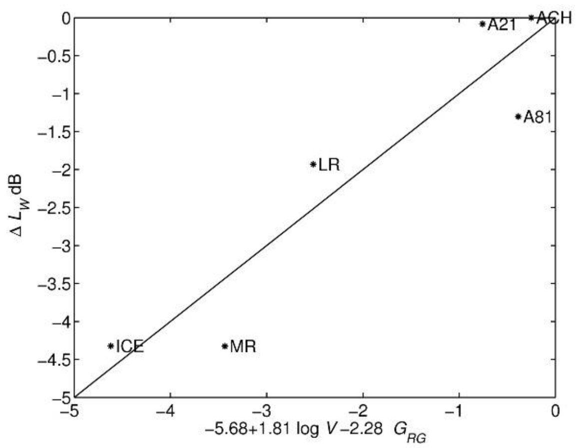

Figure 1 Regression model as compared to real data. Changes of the voice power level related to volume and room gain.

Note that the correlation between support ST as calculated in equation (1) and the other parameters is not included here as the support is undefined in the anechoic chamber due to the lack of reflexions (the value would be −∞).
The results of multi variable linear regressions for the other parameters are described below.

Log V and GRG correlates well with VPL. A multiple linear regression model using these two variables is

$$\_LW = -5.68 + 1.81 \log V - 2.28G_{RG}, \qquad (3)$$

with $R^2 = 0.86$ and $p = 0.05$. The improvement of using two parameters is described by the fact that R^2 increased from 0.78 to 0.86 and at the same time the model reached the limit of significance. The model is shown in Figure 1.

Correlation between the subjective response parameters was also calculated. It was found that SIV and SES

correlated well with S_{GSI} ; these regressions are also shown in Figure 2 and 3. A multiple linear regression model using these two variables is

$$S_{GSI} = 6.82 - 0.715S_{IV} - 0.189S_{ES}, \qquad (4)$$

with $R^2 = 0.74$ and $p = 0.13$.

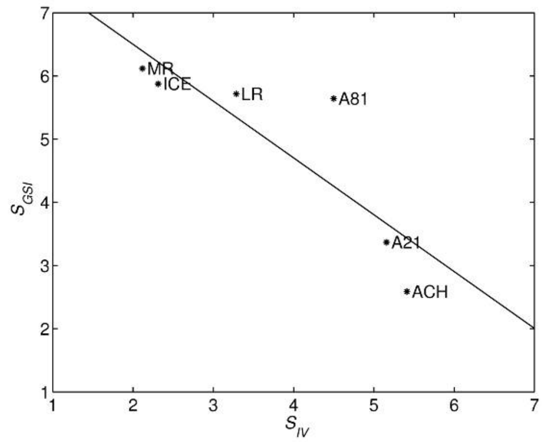

Figure 2 Regression model subjective parameter S_{GSI} against S_{IV}

The regression between IV and ΔL_W is shown in Figure 4, and between TR and T_{EDT} is shown in Figure 5. A multiple linear regression model for IV using two variables is

$$S_{IV} = -0.198 + 1.73 \log V - 1.11G_{RG}, \qquad (5)$$

with $R^2 = 0.90$ and $p = 0.03$. The improvement of using two parameters is described by the fact that R^2 increases from 0.86 to 0.90 and the model is significant.

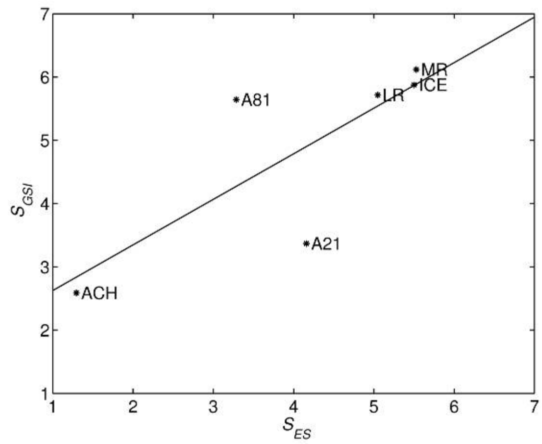

Figure 3 Regression model subjective parameter S_{GSI} against S_{ES}

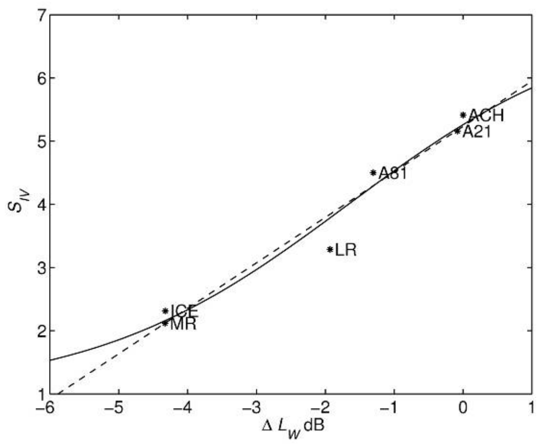

Figure 4 Regression model S_{IV} against ΔL_W.

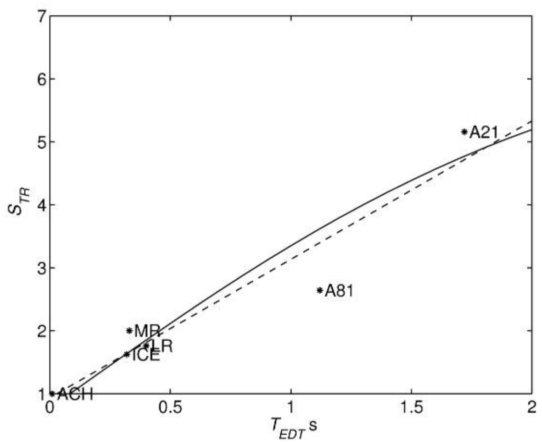

Figure 5 Regression model S_{IV} against ΔL_W.

4 Conclusions

•Using the voice power relative to the result in the anechoic chamber yields significant variations in these data.

•The increase in the voice power produced by a speaker lecturing in a room is correlated with the size of the room (especially log V) and the gain produced by the reflections in the room, GRG. These relations are significant.

•No significant correlation is found between the increase in the voice power and the reverberation time or background level of the room in this study. The latter is probably due to the too small variation in the background level in the rooms used in this study.

•The general impression of the room being good to speak in is linked to the impression of whether it is necessary to increase the voice in the room and whether the room gives support to the speaker. The former relation is significant, the latter only a trend.

•There is significant correlation between the question of whether the subject had to increase the voice and the actual increase in voice power. There are also significant correlation between the question about the reverberation in the room and the measured reverberation time. This means that the subjects participating were aware of these parameters.

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