# A Study on Voice Quality and Vocal Fatigue of Lecturers in Lecture Halls

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## Introduction

Vocal disorders are prevalent in occupational voice users such as teachers or radio moderators [1]. As the voice is an invaluable tool for these groups, a vocal disorder can be the cause for a forced career change. Concerning university teaching personnel, studies have shown that vocal disorders [2] and vocal fatigue [3] are reported more frequently. Environmental factors are however rarely considered in voice quality and vocal fatigue. These include the use of microphones to reduce the vocal load or room acoustic properties which can support a speakers voice. As of now, there are mainly studies focused on teachers [4, 5] and classroom acoustics [6], but not on lecture halls.

This study examines, if lecture hall acoustics could have an effect on vocal fatigue and overall voice quality in lecturers. Therefore, a study with the goal of assessing lecturers voice quality over a lecture was conducted. To comply with data protection laws and have genuine lecture conditions, voice samples of lecturers were recorded before and after real lectures. The vocal fatigue was examined with a questionnaire. Three lecture halls have been chosen for this study, based on their size and time of construction. H01 (935 seats) and H03 (483 seats) differ in size and are both located in the C.A.R.L. auditorium of RWTH Aachen University, which opened in 2017. "Roter Hörsaal" (473 seats) is comparable in size to H03, but finished initial construction in 1954.

## Lecture hall acoustics

Room acoustics are important for speech transmission in lecture halls. Thus, parameters have been derived from Room Impulse Response (RIR) meaurements and compared to target values suggested by DIN 18041 [7]. These parameters are the Early Decay Time $EDT$, center time $t_s$, Deutlichkeit $D_{50}$, Bass Ratio $BR$ and Speech Transmission Index $STI$. The RIRs have been measured according to ISO 3382-1 [8]. Additionally, the background noise in quiet $L_{Aeq}$ was measured. The resulting values are depicted in Table 1, together with recommended ranges for lecture halls from DIN 18041 [7]. Values outside of these ranges are highlighted. The background noise is too high in all lecture halls with video projectors as the main contributing factor. Aside from that, H01 and H03 fulfil the requirements. "Roter Hörsaal" however meets the recommendations only for the BR, indicating subpar acoustic conditions for lectures.

| Parameter | Rec. Ranges | H01 | H03 | RH |
|---|---|---|---|---|
| $EDT$ in [s] | $(0.8-1.2)\cdot T_{opt}$ | 0.97 | 1.02 | 1.38 |
| $T_{opt}$ in [s] | | 1.09 | 0.99 | 0.84 |
| $BR$ | 0.9-1.1 | 1.09 | 1.08 | 0.91 |
| $STI$ | 0.6-1 | 0.61 | 0.61 | 0.53 |
| $D_{50}$ in [%] | 50-100 | 52.14 | 51.89 | 44.96 |
| $t_s$ in [ms] | $6/7-8/7\cdot t_{s,opt}$ | 70.2 | 72.3 | 95.4 |
| $t_{s,opt}$ in [ms] | | 79 | 72 | 61 |
| $L_{A,eq}$ in [dB] | 25-30 | 34.5 | 44 | 38 |

**Table 1:** Recommended ranges for the room acoustic parameters in comparison to mean measured values for H01, H03 and "Roter Hörsaal" (RH). Values outside of recommended ranges are highlighted in red and orange respectively. The optimal values are depicted in the grey rows for each lecture hall.

A room does not only impact speech perception, but also the way a person speaks, as early reflections can increase the auditory feedback of the speaker. Thus, a variation in vocal effort induced by the Lombard effect [9] can be counteracted by early reflections at the speakers position [10]. The parameter voice support $ST_V$ has been introduced to assess this effect [11]. It uses Oral-Binaural Room Impulse Responses (OBRIRs), which are measured with a Head And Torso Simulator (HATS). These are impulse responses, which include the transmission path from mouth to ear as source and receiver respectively. They have been measured with the HMS II.3 from HEAD acoustics. A window function is then applied to the OBRIR in the time domain to separate direct ($L_{E,d}$) and reflected ($L_{E,r}$) sound energy from mouth to ear. The difference between the two resulting values is the voice support:

$$ST_V = L_{E,r} - L_{E,d} \text{ [dB]} \quad (1)$$

OBRIRs have been measured in each lecture hall from the lecturers position. To include their movement during the lecture, OBRIRs have been measured in an azimuth range of 120° with 10° steps. The resulting $ST_V$ values are depicted in figure 1. "Roter Hörsaal" has roughly 2.5dB higher voice support, while the azimuth dependency is negligible for all lecture halls.

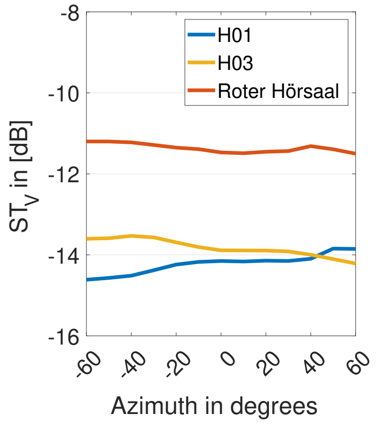


**Figure 1:** $ST_V$ values measured in the three lecture halls in relation to the azimuth.

## Study

To determine the voice quality of lecturers, speech recordings were conducted before and after real lectures. For minimal effort required by the participants and short gaps between lectures and recordings, measurements were conducted using a mobile setup next to the lecture halls. The recordings have been conducted with a headset microphone (DPA 4066-OC-A-F00-LH) and an AKG microphone on a stand (C480 B preamplifier with a CK61 ULS capsule). Participants were instructed to sit in a distance of 20 cm to the AKG microphone. After a test recording for gain adjustments, they read out loud an excerpt of the fable "Nordwind und Sonne" (often used in voice analysis [12]) followed by the vowel "a" for at least three seconds, resulting in roughly 30 second long recordings. The whole procedure took approximately 5 minutes before and 3 minutes after the lecture.

All participants filled out a questionnaire containing the VFI (German version) and questions about known voice disorders, their experience in lectures and vocal training.

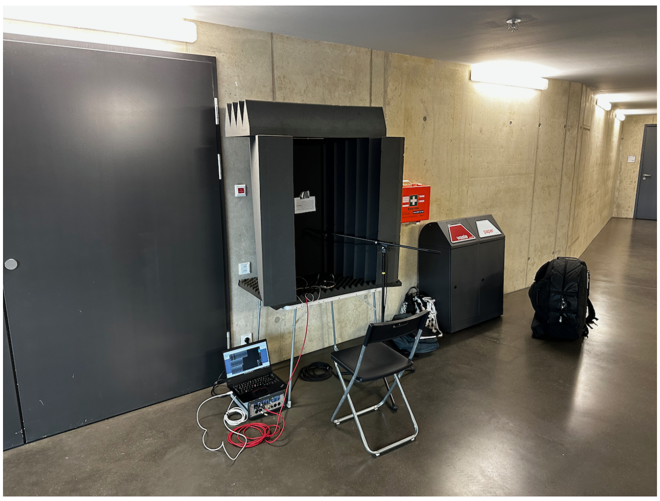

**Figure 2:** Recording setup in the room next to H01 and H03

Participants were lecturers with courses in the respective lecture halls. 33 out of 42 inquired lecturers participated (14 in H01, 7 in H03, 12 in "Roter Hörsaal"). The youngest was 25, the oldest 61 years old with an average of 41.4 years. One individual was excluded because of an existing precondition. All participants used a microphone to amplify their voice during the lecture. Attention rates in the lectures were rather good with no empty or completely full lecture halls. However, no precise data was gathered. The mean background noise during lectures at the lecturers position was 5-10dB higher than in silence.

## Voice Quality

The voice recordings have been used to asses the lecturers voice quality. They have been analysed with the software *Praat* [13] and the "Stimmprofil" plugin [14] to extract vocal features and additionally been rated by a voice therapist.

Important vocal features which have been extracted with *Praat* and analysed include the fundamental frequency $F_0$, the vocal range, Jitter, Shimmer, the Harmonics-to-Noise-Ratio HNR, the slope of the spectrum, the Smoothed Cepstral Peak Prominence CPPS and the Acoustic Voice Quality Index AVQI. As the absolute values are not reliable to make assumptions about voice quality, the values before and after lectures have been analysed statistically with a factorial mixed ANOVA. Data sets for all significant results fulfilled the requirements of this statistical model (standard distribution, sphericity and homoscedasticity). As depicted in figure 3, $F_0$ ($F = 11.122$, $p < .01$) and $HNR$ ($F = 8.112$, $p < .01$) are significantly higher after the lectures. For other vocal features, no significant effects occurred. Furthermore, there was no significant effect between lecture halls.

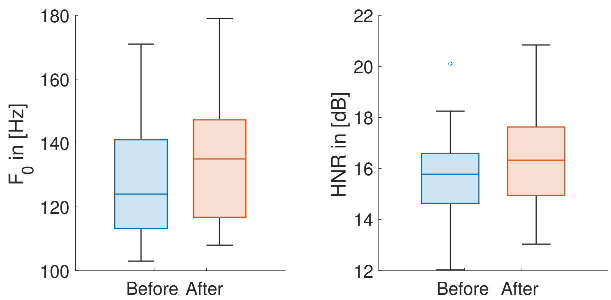


**Figure 3:** Box plots of $F_0$ (chart on the left) and $HNR$ (chart on the right) measured before and after lectures in blue and orange respectively. Both charts show a significant increase.

In addition to the statistical analysis, the voice recordings have also been rated by a voice therapist. An established method in voice therapy is the RBH scale (roughness, breathiness, hoarseness). The rating works as follows. First, a signal is presented and scored on its roughness and breathiness on a scale from 0 (none) over 1 (mild), 2 (moderate) to 3 (severe). By convention, the hoarseness score results from the highest score between roughness and breathiness. [15]

As the change in voice quality over a lecture is of interest, the resulting RBH scores before and after lectures have been compared for each participant and put into three categories: An improved score, a similar score or a worse score after the lecture. The results are depicted in figure 4. Here, a trend of more worsening scores for "Roter Hörsaal" can be observed, while most scores for the other lecture halls stayed steady over lectures.

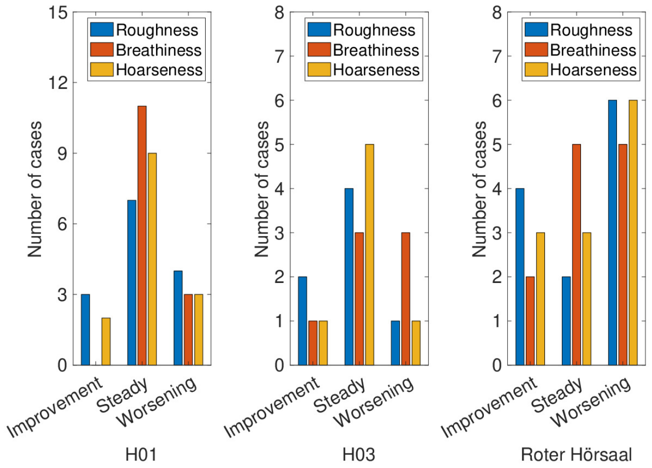


**Figure 4:** Plots of the comparisons between roughness, breathiness and hoarseness values before and after lectures in the respective lecture halls. The cases are divided in and improved, steady or worse rating after the lecture.

## Vocal Fatigue

There are two subsets of vocal fatigue. "Performance fatigue", which is physiological consequence of voice use and "perceived fatigue", which also incorporates factors like the speakers psychological state, pain or performance feedback. The latter describes the average amount of perceived fatigue over a longer time period. [16] It can be measured with the Vocal Fatigue Index (VFI), a self-evaluation questionnaire. The VFI consists 19 questions, divided into three parts. The first part focuses on the tiredness of ones voice, whereas the second part is about physical discomfort in the vocal tract. The last part emphasises the recovery of vocal fatigue with rest. Each question is answered with a score from 0 ("never") to 4 ("always").The total score for each part is then determined by addition. In the study, the verified German version of the VFI was used [17]. The results are depicted in figure 5, with values above the mean of dysphonic individuals highlighted in red and values below the average for healthy individuals highlighted in green. The mean values are apprehended from Nanjundeswaran et al., who also developed the VFI. [18]
The results show increased values for the tiredness of voice and physical discomfort in the vocal tract. The values for vocal recovery are in the range of healthy individuals.

## Discussion

The aim of this work was to examine a possible relationship between room acoustic properties of lecture halls and the voice quality of lecturers together with their vocal fatigue. Therefore, a study has been conducted. It included the acoustical evaluation of three lecture halls through objective measurements and vocal assessment of

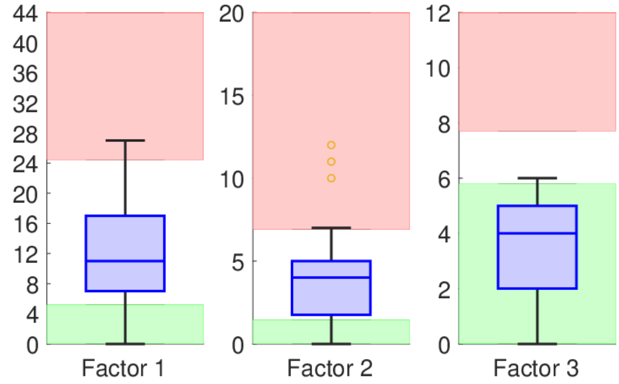


**Figure 5:** Box plots of all accumulated VFI scores, divided into the three factors. Ranges above the mean for dysphonic individuals is marked in red, ranges below the mean for healthy individuals are marked in green (according to [18]).

lecturers through a questionnaire and voice samples surrounding their lectures.
Out of the three lecture halls, H01 and H03 have broadly similar room acoustic parameters, which fulfil the recommended ranges for lecture halls apart from the background noise caused by the projectors. "Roter Hörsaal" however has substandard acoustic conditions, which impedes speech transmission.
The statistical analysis of lecturers voice recordings showed a significant performance fatigue after lectures, determined by a rise in the fundamental frequency $F_0$ [4, 5, 19]. Other voice quality parameters such as the AVQI however did not show significant differences. This could be due to a missing vocal warm-up before the first recording [20], distorting the measurements. No significant effect of the lecture halls on performance fatigue or voice quality could be detected in the analysis.
However, the ratings by a voice therapist showed more increased RBH values over lectures in "Roter Hörsaal" in comparison to H01 and H03. Although this result should be taken with caution as only one voice therapist rated the recordings, it coincides with the substandard acoustic conditions in "Roter Hörsaal".
The perceived vocal fatigue examined with the VFI was overall elevated concerning the tiredness of voice and the physical discomfort of participants. The improvement of symptoms with rest was altogether in the range of healthy individuals.
Overall, an influence of lecture hall acoustics on voice quality and vocal fatigue could not be detected statistically. In future work, voice recordings could be rated by more voice therapists, making a statistical analysis of the RBH ratings possible. Additionally, a vocal warm-up could be integrated into the study design, although participants had little time to spare before lectures.

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## References


[1] Cantor Cutiva, C. (2018). Association between occupational voice use and occurrence of voice disorders: a meta-analysis. *Areté*, 18(2):1–10.

[2] Higgins, K. P. (2006). The prevalence of voice disorders in university teaching faculty. *Electronic Theses and Dissertations 286.* https://digitalcommons.library.umaine.edu/etd/286

[3] Coelho, S. C., Depolli, G. T., Cruz, K. S., Fernandes, D. N. D. S., Costa, M. R. B., Oliveira, G., Azevedo, E. H. M., and Guimarães, M. F. (2021). Relação entre fadiga vocal e qualidade de vida relacionada à voz em professores universitários. *CoDAS*, 33(5):e20200174.

[4] Laukkanen, A.-M., Ilomäki, I., Leppänen, K., and Vilkman, E. (2008). Acoustic measures and self-reports of vocal fatigue by female teachers. *Journal of Voice*, 22(3):283–289.

[5] Moreno, M., Calvache, C., and Cantor-Cutiva, L. C. (2022). Systematic review of literature on prevalence of vocal fatigue among teachers. *Journal of Voice.*

[6] Pelegrín-García, D., Brunskog, J., Lyberg-Åhlander, V., and Löfqvist, A. (2012). Measurement and prediction of voice support and room gain in school classrooms. *The Journal of the Acoustical Society of America*, 131(1):194–204.

[7] DIN 18041 (2016). DIN 18041:2016-03 Hörsamkeit in Räumen - Anforderungen, Empfehlungen und Hinweise für die Planung.

[8] DIN 3382-1 (2009). DIN EN ISO 3382-1:2009-10 Akustik – Messung von Parametern der Raumakustik – Teil 1: Aufführungsräume.

[9] Lombard, E. (1911). Le signe de l'elevation de la voix, Annales des Maladies de l'Oreille, du Larynx, du Nez et du. *Pharynx*, 37:101–119.

[10] Bottalico, P., Graetzer, S., and Hunter, E. J. (2016). Effects of speech style, room acoustics, and vocal fatigue on vocal effort. *The Journal of the Acoustical Society of America*, 139(5):2870.

[11] Pelegrín-García, D. (2011). Comment on "Increase in voice level and speaker comfort in lecture rooms" J. Acoust. Soc. Am. 125, 2072-2082 (2009) (L). *The Journal of the Acoustical Society of America*, 129(3):1161–1164.

[12] Anders, L. C. (2012). Perzeptive Beurteilung der Stimme. *Seidner, Wolfram/Nawka, Tadeus: Handreichungen zur Stimmdiagnostik. Berlin: Xion.*

[13] Boersma, P. and Weenink, D. (1992-2023). Praat: doing phonetics by computer [Computer program]. Version 6.3.12, retrieved 24 July 2023 from http://www.praat.org/.

[14] Mayer, J. (2019). Praat-Stimmprofil.

[15] Ptok, M., Schwemmle, C., Iven, C., Jessen, M., and Nawka, T. (2006). On the auditory evaluation of voice quality. *Hno*, 54:793–802.

[16] Hunter, E. J., Cantor-Cutiva, C., van Leer, E., van Mersbergen, M., Nanjundeswaran, C. D., Bottalico, P., Sandage, M. J., and Whitling, S. (2020). Toward a Consensus Description of Vocal Effort, Vocal Load, Vocal Loading, and Vocal Fatigue. *Journal of speech, language, and hearing research : JSLHR*, 63(2):509–532.

[17] Stappenbeck, L., Finck, G., Bartel, S., and Brockmann-Bauser, M. (2021). Pathologische Stimmermüdung: emotionale und physische Merkmale. *Sprache· Stimme· Gehör*, 45(02):82–88.

[18] Nanjundeswaran, C., Jacobson, B. H., Gartner-Schmidt, J., and Verdolini Abbott, K. (2015). Vocal Fatigue Index (VFI): Development and Validation. *Journal of voice : official journal of the Voice Foundation*, 29(4):433–440.

[19] Anand, S., Bottalico, P., and Gray, C. (2021). Vocal fatigue in prospective vocal professionals. *Journal of Voice*, 35(2):247–258.

[20] Laukkanen, A.-M., Järvinen, K., Artkoski, M., Waaramaa-Mäki-Kulmala, T., Kankare, E., Sippola, S., Syrjä, T., and Salo, A. (2004). Changes in voice and subjective sensations during a 45-min vocal loading test in female subjects with vocal training. *Folia phoniatrica et logopaedica*, 56(6):335–346.