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Acoustic refurbishments in a university lecture room: Effects on speaker's comfort and voice strain

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ABSTRACT

Poor acoustic conditions in educational spaces negatively impact speakers' health and pose a risk for voice disorders. However, there are limited studies on the effect of acoustic renovations on speaker's comfort and well-being in real settings. This sub-study, part of a larger dissertation project, investigated how different acoustic conditions affect speakers' comfort and voice strain. Method: Acoustic renovations were measured in four stages: Baseline, Step 1 (Absorbers on walls and ceiling), Step 2 (Absorbers + acoustic ceiling with reflectors at the speaker's position), Step 3 (Absorbers + ceiling with diffusers at the speaker's position). Fifteen participants (7F/8M) gave short presentations under four conditions: silence, background noise (babble), with a sound field amplification system (SFAS), and with both a SFAS and background babble-noise. Voices were recorded, and speakers rated their voice strain and comfort. Results: Using mixed linear models, we found statistically significant improvements in perceived comfort after renovations, with differences between baseline and Steps 2 and 3. Speaker's comfort decreased with background noise, and women reported greater discomfort than men in these conditions. In summary, improved acoustics positively impact speakers, with results highlighting the importance of good acoustic environments in educational settings.

Keywords: *Room acoustics, Background noise, Speaker's comfor*

1. INTRODUCTION

Despite poor room acoustics being a risk factor for voice disorders among occupational voice users [1], and impacting both teachers and students negatively [2-3], the acoustics of the learning spaces is suboptimal or even poor [4]. Previously, the focus on the impact of classroom acoustics has been on students. However, prior research suggests that classroom acoustics optimized for listeners—such as lower reverberation times and higher speech clarity—do not necessarily create better conditions for speakers [5-6].

A speaker's perception of their voice is influenced by the acoustics of the environment. *Speaker's comfort*, meaning the speaker's perception of when the spoken message reaches the listener effectively, with little or no vocal effort, is influenced by factors such as room acoustic support, speech intelligibility, and sensory-motor feedback from the speaker's phonatory apparatus [7-8]. The aim of this study was to investigate how different acoustic conditions affect speakers' comfort.

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2. METHOD

Fifteen participants (7F/8M, mean age 35 years) with previous experience in public speaking, such as lecturing or presenting, were recruited for the study. The study was conducted as a repeated measures design in a university lecture room undergoing a three-step acoustic refurbishment.

2.1 Acoustic refurbishment of the university lecture room

The university lecture room had the dimensions 7.2 m x 5.6 m x 4.1 m and seated approximately 22 persons. The lecture room underwent a three-step acoustic renovation, with data collection and room acoustic measurements (T_{20}, C_{50},) conducted prior to the renovation (baseline), and at each step of the renovation, including step 1 (absorbers), step 2 (reflectors) and step 3 (diffusers). In summary, the room had 20 mm thick absorbers on walls and 40 mm thick absorbers on the ceiling at baseline. In the first step, old wall absorbers were replaced with thicker, 40 mm sound-absorbing panels, and a suspended ceiling with 40 mm thick absorbers were installed between ceiling beams, with two additional layers (50 + 50 mm) of low-frequency absorbers above the suspended ceiling. Additionally, an empty grid ceiling was installed above the speaker position. In step 2, flat gypsum panels, called reflectors, were installed in the grid ceiling. In step 3, the reflectors were replaced by vertically oriented wooden diffusers. There were 5 – 8 weeks between each step in the refurbishment. In summary, the largest changes in T_{20} and C_{50} were observed in the lower frequencies, and changes were largest between baseline and steps 1-3. See Table 1. For T_{20} and C_{50} measurements in the 250 Hz frequency band. For more information on the refurbishment and acoustic measurements T_{20} and C_{50} pre- and post-refurbishment, see Christensson [9].

Table 1. Room acoustic measurements (T_{20}, C_{50}) at 250 Hz, in baseline and each step of the refurbishment

Acoustic refurbishment	T20	C50
Baseline	1.55	-3.65
Absorbers	0.84	1.04
Reflectors	0.87	0.66
Diffusers	0.73	2.25

2.2 Study design

The participants performed a set of three short speech tasks in front of a small audience (1-4 people) before the acoustic refurbishment (baseline), and at each step of the acoustic refurbishment (steps 1-3), in total four time points. At each time point, the participants performed the set of speech tasks four times, during four different experimental conditions. See Table 2. for the experimental conditions. As a result, participants performed the speech tasks in total 4 x 4 times (4 time points x 4 experimental conditions). The speech tasks included a describe-and-draw task, where participants explained a complicated geometric figure in approximately 3 minutes for the audience, while the audience tried to draw this figure. After this, participants were asked to give an oral presentation of an exotic or fantasy animal using presentation slides unknown to them. The participants prepared for this task by reading a short informative paper on the animal in question. Lastly, participants did a STROOP task with 40 items. A different variation of the speech tasks was used at every time point and condition, and the order was randomized for each participant.

Table 2. Experimental conditions

Condition	50 dB(A) background babble noise	SFAS use
Silence	No	No
Noise	Yes	No
Silence + SFAS	No	Yes
Noise + SFAS	Yes	Yes

The babble noise used in conditions Noise and Noise + SFAS was non-semantic and multitalker. The babble was played from a loudspeaker placed on a table near the back door of the lecture room. The loudness of the babble noise was 50 dB(A) at the speaker's position (in front of the lecture room). The loudspeaker for the SFAS (Vox Duo, (Sensio Vestfold, Sandefjord, Norway) was placed in front of the lecture room, on a stool in front of the whiteboard. Participants' voices were recorded using a head-mounted microphone. After each condition, participants were asked to answer a questionnaire regarding the perceived acoustics of the room and their speakers' comfort.

2.3 Speaker's comfort questionnaire

The questionnaire included statements about the perceived room acoustics, vocal strain and comfort, perception of speech tasks, and SFAS use. Statements were answered using a 5-point Likert scale. A factor analysis was conducted on the items in the questionnaire, which yielded a two-factor solution. The first factor included statements on perceived room acoustics and vocal comfort/strain. The second factor included statements on task experience (e.g. "I succeeded well in the task I had to perform"). Speaker's comfort was operationalized as the sum scores for statements that loaded on the first factor, see Table 3 for the included statements. Negative statements were converted to positive, and the sum scores were then converted to z-scores, and higher scores were interpreted as higher speaker's comfort for participants. More information on the factor analysis can be found in Cansu et al. [10].

Table 3. Statements included in the speaker's comfort factor

Statement
The room acoustics helped me to speak comfortably
I had to make an effort to be heard in the space
It felt like my voice was muffled by the acoustics of the space
The sound environment in the space made me tired
I had to work hard to perform the way I did

2.4 Statistical analysis

The effect of room acoustics, babble noise, and SFAS use on speaker's comfort was investigated using linear mixed effects models in R version 4.3.2. Two- and three-way models were compared and assessed using the analysis of variance function and comparing the Akaike information criterion (AIC), so that the lower the AIC score, the better the model fit [11]. Room acoustics, babble noise, SFAS, and sex were used as *fixed effects* in the models, while participant was considered a *random effect* to account for within-participant variation.

3. RESULTS AND DISCUSSION

Our results suggest that participants' speaker's comfort increased significantly in the second (reflectors), and third step (diffusers) of the acoustic refurbishment. Additionally, speaking in silent conditions compared to noisy conditions had the largest impact on speaker's comfort, with significantly increased speaker's comfort in silent conditions. For an overview of results from the best-fitted model for speaker's comfort, see Table 4.

Table 4. Summary results for the mixed model fitted for speaker's comfort (z-scores). RA=Room acoustics

Fixed effects	β, [CI]	p-value
RA [absorbers]	0.33 [-0.18,0.83]	ns
RA [reflectors]	0.81 [0.30,1.32]	0.002
RA [diffusers]	0.64 [0.12,1.17]	0.017
Babble noise [no]	1.63 [1.19, 2.07]	<0.001
Sex [male]	0.52 [-0.10,1.15]	ns
SFAS [yes]	0.16 [-0.28,0.60]	ns
Babble noise:Sex	-0.55 [-0.88,-0.23]	0.001

Although the addition of absorbers in step 1 altered acoustic parameters (T_{20} and C_{50}) compared to baseline, significant improvements in speaker's comfort were only observed with reflectors and diffusers (step 2 and 3) in the room. Similarly, Bottalico et al. found that placing reflective panels close to speakers enhanced participants' self-perceived vocal clarity [12]. Post-refurbishment, acoustic parameters remained similar in our study, suggesting other acoustic measurements than reverberation time and speech clarity are more influential for speakers. The aim of the reflectors and diffusers was to increase the amount of early reflections in the room, which have been linked to increased signal-to-noise ratios in rooms and improved speech intelligibility [13-14]. Our data suggests that early reflections are likewise important for the speaker, since they reinforce the speech signal, thus improving auditory feedback. With stronger auditory feedback of speech, speakers would feel less need to increase their vocal effort, thus increasing speaker's comfort. However, to confirm this, speaker-oriented measurements such as voice support are needed [15].

Our results also suggested an interaction between background babble noise and the sex of the participant. In our data, females reported lower speaker's comfort in noise compared to males, while males and females reported similar levels of speaker's comfort in silent conditions. Sex differences in noise have been investigated before, and previous findings indicate that females find it more difficult to make themselves heard in noise and experience a higher subjective level of vocal effort compared to males [16].

In summary, our findings suggest that incorporating reflective materials near the speaker can be an important factor in improving speaker's comfort and optimizing room acoustics for teachers in learning spaces.

Moreover, it is important to consider sex differences when investigating the effect of noise on the speaker.

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