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Associations between classroom conditions and teacher's voice production

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Abstract

In this study, associations between classroom conditions and teachers' voce use were researched (N=40). Acoustic variables were reverberation time (T_{60}), early decay time (EDT), sound strength (G), the ratio of early and late sound energy arriving to a listener (C_{50}), the ratio of early arriving sound energy to overall sound energy (D_{50}), speech transmission index (STI) and rate of spatial decay of sound pressure levels (DL_2). Indoor climate was also evaluated. Voice variables measured were sound pressure level (SPL), fundamental frequency (F_0) and spectrum slope. According to findings when the values of T_{60}, EDT and DL_2 were lower or the values of C50, D50 and G higher, teachers' voice SPL was higher. When reverberation times were longer, F_0 increased and when the values of C_{50} and D_{50} were higher, men's F_0 was higher. Poor indoor air increased occurrence of laryngitis. The results showed that indoor environment affects voice use and thus, is associated with the health of voice organs.

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Keywords: Classroom; acoustics; voice; teachers, indoor climate

Introduction

Indoor environment and activity in classrooms are an area where many fields of science meet, from those studying human behaviour to the ones studying physical constructions and buildings. Classroom acoustics has been researched from the perspective of pupils' learning, especially. Another point of view of room acoustics is teaching, where voice use comes to a focus. Health voice is not only a matter of importance for teachers, but it affects also pupils: if a speaker's voice quality is dysphonic, children's linguistic-cognitive performance deteriorates [1]. Good

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voice ergonomics is also good for listening and learning. Voice ergonomics studies factors that may increase the risk for voice disorders [2].

A factor known to threaten the most voice health is noise. Noise loads voice [3] and increases the number of voice symptoms in teachers [2,3]. Noise also raises voice sound pressure level (SPL) and fundamental frequency (F_0) [4,5] and changes sound spectrum of voice (energy level shifts to higher frequency bands) [6].

Poor room acoustics increase noise, especially excessively long reverberation (5]. In poorer acoustic conditions, speakers use louder voice, have longer speaking times [7] and have more voice symptoms [8] than in better conditions. In turn, an acoustically good room supports voice production [9].

The voice is also affected by indoor climate. Indoor air is poor in many European schools [10] and visible mould has been found in 13.9% to 39.1% in buildings, for instance [11]. Exposure to toxic substances of mold [12] or to organic dust cause voice symptoms [13]. Dry indoor air – a problem of Nordic countries during winter – is also a risk for voice disorders. It stiffens the cover of vocal folds and increases the viscosity of mucosa [14], which in turn deteriorates the vibration of vocal folds [15].

Although studies have shown the effect of indoor environment on human behaviour there are only few voice ergonomic research on the topic. Hence, the aim of this research was to study connections between classroom conditions – acoustics and indoor climate − and acoustic parameters of voice. Classrooms with higher and lower noise were also studied separately. The study was found to be ethically safety to participants.

2. Materials and methods

2.1. Teachers and schools

Forty teachers and their classrooms were studied in the research. Of the teachers, 32 were women (mean age 45 years, range 27–57) and 8 men (mean age 39 years, range 31–45). The mean number of pupils was 20 per classroom. Nine teachers had worked less than five years, others over that. Fourteen participants (36%) reported hoarse and 21 (54%) tired voice at least weekly.

The classes were from 14 schools in 5 different cities. The sizes of the rooms were quite similar (Table 1). Because noise level has been shown to be the most important factor affecting voice use in teachers [7], on the basis of L_{90} the classrooms were divided in two groups: noisy (n=23) and quiet ones (n=17). The parameters of rooms acoustics analysed in this study did not differ between the two classroom groups (Student's *t*-test; see Table 4 for acoustic variables).

Table 1. Classroom (N=40) dimensions

Magnitude	Mean	SD	Min	Max
Room length (m)	8.4	1.0	6.8	10.20
Room breadth (m)	7.5	0.9	6.1	10.00
Room height (m)	3.2	0.24	3.0	3.80

2.2. Variables of classrooms

Acoustic variables (Table 2) and noise levels were measured with the precision sound level meter of 01dB-Stell Symphonie and 01dB-Stell Harmonie placed in the centre of the classroom. Reverberation T_{60}(s) was measured in accordance to standards ISO 354 and ISO 3382 and STI in accordance to the Standard IEC 60268-16:2003. Noise caused by pupils (L_{90}), also called activity noise in this study, was measured during lessons (measured time 2−6 hours).

2.3. Indoor climate and respiratory tract diseases

Indoor climate assessment was performed in compliance with the *Voice Ergonomic Assessment in Work Environment - Handbook and Checklist* [2]. The total number of risk factors was 16 (Table 3). The finding of a risk factor was assessed dichotomicly (0 = no risk, 1 = risk of voice disorder). Respiratory tract diseases were studied by asking if participants were given the diagnosis of laryngitis in the past 12 months (answers ‘‘yes/no’’).

Table 2. Acoustic variables measured in classrooms

Room acoustic parameter	Symbol	Unit	Definition
Reverberation time	T_{60}	second [s]	The time during which the sound level decreases by 60 dB after the sound source has ceased to operate.
Early decay time	EDT	second [s]	The time during which the sound level decreases by 10 dB after the sound source has ceased to operate.
Sound strength	G	decibel [dB]	Describes the sound volume of sound source at the distance of 10 meters compared to that at the same distance in an anechoic room.
Clarity of speech	C_{50}	decibel [dB]	The ratio of early and late sound energy arriving to the listener, that is, the energy that arrives during the first 50 milliseconds. Describes clarity of perceived speech sound.
Deutlichkeit	D_{50}	per cent [%]	Ratio of early arriving sound energy to overall sound energy. Describes perceived clarity of speech.
Speech transmission index	STI	-	Speech intelligibility between a speaker and a listener. Describes the quality of speech transmission from the point of view of syllable distinction.
Rate of spatial decay of sound pressure levels	DL_2	decibel [dB]	Rate of spatial decay of sound pressure levels per distance doubling. Describes sound attenuation when distance from the sound source doubles.

Table 3. Risk factors of indoor climate. Scoring: a factor causes risk for a voice disorder =1; no risk = 0.

Risk factor	Number of factors
Room temperature outside the range of 20–23° C	1
Dust in air/on surfaces, decoration material in room, articles difficult to clean	4
Unpleasant odours, signs of water leaks, earlier water leaks	3
Stuffy air, heavy feeling in head, draught, faulty intake /outlet of air vent	5
Dry indoor air, dry eyes, irritated eyes	3
Total number of risk factors in indoor air quality	**16**

2.4. Voice samples and acoustic analyses

The participants read a 102-word-long text before and after a working day. The recording was made with a Zoom-H2 and a headset microphone (AKG CL-555) located at the distance of 3 cm from the corner of the mouth. The recordings were calibrated (generator BOSS TU-120; a sound level meter Brüel & Kjær 2206).

From the voice samples, F_0, SPL and the tilt of a sound spectrum slope (alpha ratio) were analyzed. Alpha ratio is the relationship of voice energy levels between the level of 50 Hz–1 kHz and the level of 1–5 kHz and expresses voice quality (hypo/hyperfunctional quality; higher value expresses more hyperfunctional voice quality). F_0 was analysed separately for men and women. In addition, the change of the value of a voice parameter during work was also taken as one variable. The acoustic analyses were made with Praat-program (version 5.3.18).

2.5. Statistical analysis

The associations were studied with either Spearman correlation rank coefficient or Pearson product-moment correlation coefficient. The effect of indoor climate was calculated with Wilcoxon signed rank test.

3. Results

3.1. Values for variables of voice, room acoustics and activity noise

Participants' mean voice SPL was 67 dB (SD 5.4 dB) before and 69 dB (SD 4.3 dB) after work. Mean F_0 for females was 182 Hz (SD 15.7 Hz) before work and 185 Hz (SD 17.2 Hz) after it; for males the values were 97 Hz (SD 11.6 Hz) and 102 Hz (SD 14.9 Hz), respectively. Alpha ratio values were before work -15.7 dB (SD 1.28 dB) and after it -15.2 dB (SD 2.06 dB). Table 4 presents the values of acoustic variables and noise (L_{90}) in the classrooms.

Table 4. The values of acoustic variables and noise in the classrooms (N=40).

	T_{60} (s)	EDT (s)	G (dB)	C_{50} (dB)	D_{50} (%)	STI	DL_2 (dB)	L_{90} (dB)
Mean	.55	.53	15	4.5	73	.74	2.8	42
SD	.114	.118	2.8	1.56	6.7	.036	.86	4.1

3.2. Associations between room acoustics and voice parameters in all classrooms

The longer the reverberation time (T_{60}) and the higher the DL_2 value, the lower the voice SPL (Table 5). F_0 correlated negatively with T_{60} but positively with the variable expressing speech clarity (C_{50}). However, in classrooms with longer $T_{60,}$ teachers' F_0 has increased more during a working day. Activity noise (L_{90}) correlated with no voice variables.

Table 5. Association between room acoustic variables and parameters of teachers' voices before and after work, and the change during work, M=males, ns= not significant (N=39−40).

Room acoustic parameter	Voice SPL		F_0		
	Before	After	Before	After	Change
T_{60}	ns	-.29 (.037)	ns	-.62 (.05) ^{M}	.29 (.036)
C_{50}	ns	ns	ns	.64 (.045) ^{M}	ns
D_{50}	ns	ns	ns	.66 (.038) ^{M}	ns
DL_2	-.28 (.042)	-.37 (.011)	.65 (.039)^M	ns	ns

3.3. Associations between room acoustics and voice parameters in noisy and quiet classrooms

Noisy classrooms The mean activity noise level (L_{90}) was 45 dB (SD 2.5 dB) for the noisy classrooms. The variables of room acoustics were associated only with voice SPL and mainly after work (Table 6). In the classrooms where reverberation times (T_{60}, EDT) were longer, the teachers' voice SPL was lower after work. In turn, if listening conditions were better (increase in the values of C_{50}, $D_{50,}$ STI), teachers used higher SPL either before or after work.

Table 6. Associations between acoustic variables of loud classrooms and teachers' voice SPL before and after work, ns= not significant, (n= 21−22).

Room acoustic parameter	Before	After
T_{60}	ns	-.6 (.002)
EDT	ns	-.55 (.004)
G	.35 (.05)	ns
C_{50}	ns	.54 (.004)
D_{50}	ns	.55 (.004)
STI	ns	.51 (.007)

Quiet classrooms The mean activity noise level (L_{90}) was 38 dB (SD 3 dB) for the quiet classrooms. In these classrooms, room acoustic parameters correlated with more voice parameters than in the noisy classrooms. The strongest connection was between T_{60} and F_0 change during a working day: the longer the reverberation time, the more the teachers' voice pitches increased during work (Table 7). The teachers used louder voice after work if room sound strength (G) had higher values and the rate of spatial decay of SPL (DL_2) lower ones. In addition, the lower the values of the clarity of speech (C_{50}), the smaller was the spectrum slope tilt meaning that voice quality changed into more hyperfunctional direction during a working day.

Table 7. Association between room acoustic variables of quiet classrooms and parameters of teachers' voices before and after work, and the change during work, ns= not significant (n= 17–18).

Room acoustic parameter	Voice SPL	F_0	Alpha ratio
	After	Change	Change
T_{60}	ns	.51 (.018)	ns
G	.42 (.047)	ns	ns
C_{50}	ns	ns	-.47 (.029)
DL_2	-.49 (.024)	ns	ns

3.4. Indoor climate

Median number of risk factors for indoor climate was 8 (range 0−12). The risk factors most often found in classrooms were *materials collecting dust or difficult to clean* (90 % of the classrooms) and *dust on surfaces* (85 %). Air was often also *stuffy* (72.5 %) and *dry* (70 %). Teachers who worked under poorer indoor climate, have had more often laryngitis during past year than those with better climate ($p=0.051$; $z=1.994$).

Discussion

Our results showed that indoor environment is associated with teachers' voice production and good indoor climate increases vocal health. Especially voice SPL seems to be a feature that reacts to room acoustics and indoor climate. In addition, activity noise affects how the influences of room acoustics emerge: in the noisy classrooms, the connections were found only with voice SPL, but in the quiet ones, more voice parameters were affected by room acoustics. Increasing voice SPL may be relatively unconscious reaction of a speaker to demanding speaking conditions, such as noise triggers so called Lombard effect [16].

Of the acoustic variables T_{60}, EDT, C_{50}, D_{50}, STI affected voice similarly: it they indicated poorer room acoustics, the teachers' voice SPL was lower. This suggests muscle fatigue in voice organs. Furthermore, if reverberation times were long, the teachers had a tendency to raise voice pitch that may be a reaction to increased noise levels due to poor attenuation [4,5]. Reverberation time is typically the only parameter that is described in regulations for acoustics in classrooms. However, reverberation time is neither a direct predictor of speech intelligibility, nor of activity noise levels during classes. In this study, nevertheless, it was connected to the teachers' voice production.

The findings regarding T_{60} and DL_2 and voice SPL were somewhat contradictory. Namely, the results showed that when the rooms were more reverberant (T_{60}) and sound attenuation (DL_2) was bigger, the teachers used lower voice SPL. If the space is reverberant, speech voice carries easily far, and if the rate of spatial decay of sound pressure levels per distance doubling is high, the speech sound is attenuated. On the other hand, T_{60} and the rate of DL_2 measure different entities. This gets support from our post hoc analysis according to which T_{60} and DL_2 did not correlate with each other in this data.

F_0 (from the samples before and after work) was analysed for the genders separately. Only men's voice pitch reacted to room acoustics primarily. The poorer acoustics on the basis of the parameters of T_{60}, C_{50}, D_{50}, DL_2, the lower the men's F_0. This may originate from tissue damage of vocal folds (increased oedema) or from the teachers attempt to increase authority in noisy environment.

Higher sound strength (high G value) was connected with higher voice SPL. Interestingly, those working in the noisier classrooms already used louder voice before work but those worked in the quieter ones had increased voice SPL during a working day (found in voice samples after work). The first mentioned teachers' voice may reveal a long-term effect of noise because of higher sound strength (that intensifies both noise and speech voice), possibly due to swollen vocal folds that leads to increased phonation threshold pressure and further, forces to use high subglottic pressure and consequently, higher SPL. The latter mentioned teachers' voices, in turn, probably showed a more direct (acute) loading effect.

The variable indicating voice quality (alpha ratio) was associated with the parameter descripting perceived clarity of speech (C_{50}). The better the clarity, the more hypofunctional was the voice production, which means less loading of voice organs.

There are some methodological considerations regarding the findings. The results revealed long-term consequences due to indoor environment rather than direct ones because most of the participants had worked as teachers years before this research. There are also several risk factors that affect voice production other than found in working environment. Furthermore, our findings cannot not be generalized completely due to the small number of classrooms and teachers.

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