The effects of classroom acoustics, including low frequency noise, on teachers' voice parameters

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Summary

The acoustic design of schools has traditionally focused on enabling pupils to hear the teacher. However, given the high prevalence of voice problems among teachers, there is also a need for those involved in the acoustic design of classrooms to consider voice ergonomics for teachers.

A recent study undertook measurements of teachers' voices in classrooms with different acoustic properties to examine possible correlations between voice and classroom acoustics parameters. The majority of the classrooms involved met current acoustic standards for newly constructed classrooms in England.

The mean voice level measured was classified as 'loud' (based on guidance values) and the participants spoke for a large proportion of the day (average 21%). The female participants spoke at higher levels than the male participants which is contrary to the average voice levels for the wider population. These factors indicated that the participants were using their voices in ways which were different to 'normal' non-occupational voice use.

Those teaching younger aged children spoke both at higher levels and for a larger proportion of the teaching day which may indicate elevated risks of voice problems in this group.

There were no correlations between reverberation time parameters and voice characteristics.

However, participants teaching in rooms with higher unoccupied noise levels spoke at a higher sound level. There was a significant, positive correlation between voice levels in female participants and unoccupied noise levels in the same region of the noise spectrum as the fundamental frequency of the female voice. The data suggested a similar relationship for male participants. This indicated that the control of low frequency noise levels and reverberation times (not currently covered by school acoustics guidance documents in the UK) may be important in reducing voice levels and the associated vocal risks.

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1. Introduction

This paper details research undertaken by the Acoustics Group at London South Bank University which investigated the effects of classroom acoustics on teachers' voice parameters.

There are a number of sources of guidance in relation to classroom acoustic design in England including Building Bulletin 93 (BB93) [1] and the School Premises Regulations (SPRs) [2], both of which refer to teachers' voice problems.

Table I. BB93:2015 acoustic criteria for classrooms when unoccupied by school type and classroom type [1].

	Unoccupied ambient noise level $L_{Aeq,\ 30\ minutes}$ dB		Unoccupied reverberation time T_{mf} seconds	
Pupil age	New	Refurbishment	New	Refurbishment
Primary school (age 5–11)	≤ 35	≤ 40	≤ 0.6	≤ 0.8
Secondary school (age 11–18)	≤ 35	≤ 40	≤ 0.8	≤ 1.0

The SPRs in Regulation 7 state:
'*The acoustic conditions and sound insulation of each room or other space must be suitable, having regard to the nature of the activities which normally take place therein*'.
A guide to complying with the requirements of the SPRs [3] states that this regulation means that:
'*In classrooms, class bases and other areas used for teaching, this will allow teachers to communicate without straining their voices*', however no practical guidance on how this is achieved is given in the document.
In BB93 it is stated that
'*Poor acoustic conditions in the classroom increase the strain on teachers' voices as most teachers find it difficult to cope with high noise levels. This often leads to voice problems due to prolonged use of the voice and the need to shout to keep control*'.
As with the SPRs, BB93 does not give guidance on how acoustic conditions can be designed to consider teachers' voices.
For information the main BB93 acoustic criteria for classrooms in terms of unoccupied noise levels (termed UANL in this paper) and reverberation times at mid-frequencies (the mean of 500 Hz, 1 kHz and 2 kHz octave bands) are shown in Table I. It is notable that the criteria relate to A-weighted noise levels and mid-frequency reverberation times only and that criteria in the spectral domain are not given.

2. Classroom and voice measurements

2.1 Participant selection

Teachers were selected to participate in this study who taught in a range of classroom types. These ranged from classrooms constructed in the late 1800s to those constructed, or refurbished, in recent years with better acoustic conditions.
Many of the oldest classrooms remained as originally constructed with what would now be considered poor acoustic design. This included single pane windows which offered relatively poor sound insulation from external noise, and ventilation openings without acoustic attenuation as well as a lack of sound absorption for reverberation control.
All classrooms were naturally ventilated without mechanical ventilation or air conditioning.
Twenty teachers were measured in total in the study. All taught full time and were fully qualified. Four participants taught in a secondary school and sixteen in primary schools. All teachers taught in classes with no more than 33 pupils.
The project involved a number of different strands of data collection which are summarised in the following sections, and was approved by the University Research Ethics Committee.

2.2 Measurements of unoccupied room acoustic parameters

Acoustic measurements were made in the classrooms, while unoccupied, in which the participating teachers taught. These were typically made during school holidays to avoid noise generated by school activities as per the BB93 criteria in Table I. The classrooms were measured with the regular furniture and equipment in place.
Software based measurements of room impulse responses were also made to allow a variety of room acoustic parameters to be calculated including reverberation times which were used to determine the T_{mf} value in line with the criteria in Table I.
Measurements of unoccupied ambient noise levels were made with a Class 1 sound level meter and were undertaken during representative periods of ambient noise.

2.3 Measurements of occupied room acoustic parameters

During the working day when the teacher's voice was being measured the general activity noise levels in the classroom were measured simultaneously. This was carried out using a Class 1 sound level meter installed at the most distant pupil position from the teacher in the classroom. This was normally at the rear of the room and was chosen as having the worst case (lowest) signal to noise ratio between the teacher's voice and the ambient noise in the room. The sound level meter automatically measured sound pressure level data in both 1 second and 1 hour intervals simultaneously in A-weighted and spectral values. To comply with the ethical approval conditions, and to simplify issues of consent and privacy, audio recording was not used on the sound level meter. In addition, to avoid influencing the normal classroom dynamic the researcher was not present in the classroom during the measurements. The teacher gave feedback to the researcher at the end of the measurement day as to the nature and timing of different activities undertaken during that teaching day.

The sound level meter was installed prior to lessons commencing and retrieved after the end of the school day. During post processing only the lesson period data was analysed.

2.4 Measurements of teachers' voice parameters

The measurement methodology, which is described in more detail by Durup *et al* [4], is summarised in this section.

Each teacher was measured during what they identified as a typical working day, carrying out normal activities in their usual classroom. Measurements were made typically from 09:00 to 15:00 hours during core teaching hours and did not include preparation time, meetings and other activities outside these times.

In order to measure the voice level of the participant only, it was identified that voice parameters could be measured using an ambulatory phonation monitor (APM). In this study the KayPENTAX 3200 APM and 3203 accelerometer were used to undertake measurements.

The APM is a device which measures vibrations from the voice using a small accelerometer fixed

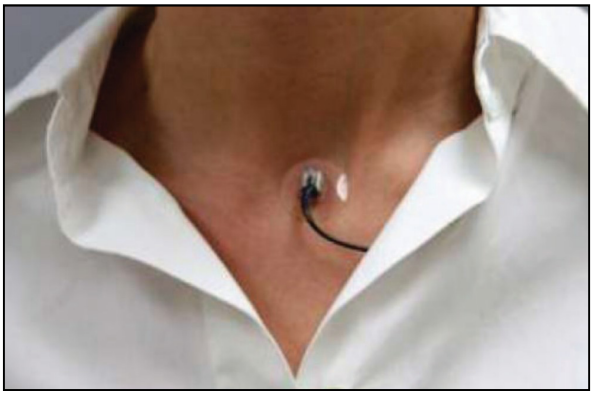

Figure 1. APM accelerometer fitment [5].

to the skin over the participant's sternal notch as shown in Figure 1.

The APM was calibrated prior to the measurements, in a room with suitably low ambient noise levels, using a calibrated microphone mounted at a fixed distance (0.15 metre) from the participant's mouth, - allowing voice parameters to be calculated subsequently from the measured acceleration.

Following calibration the participant wore the accelerometer for their working day attached to a small unit on their waist.

The APM monitors a number of speech parameters including the estimated linear average sound pressure level (L_{pZ}) and the fundamental frequency of the voice (SF_0). In addition the APM measures the phonation time, which is the total speaking time during the measurement excluding pauses between words and syllables, and the phonation percentage which is the proportion of the measurement period for which the teacher was speaking. The APM unit is supplied with proprietary software which carries out analysis as well as allowing the raw acceleration data and transfer functions between acceleration and L_{pZ} to be exported for analysis in other software.

For analysis purposes a correction (–16.5 dB) was applied to normalise the voice level data to 1 m from the mouth.

3. Results

The results of the classroom acoustic measurements and those of the measurements of the teachers' voice parameters are summarised in Table II. Spectrum data for the UANLs and occupied noise levels are omitted for brevity.

The unoccupied ambient noise levels ranged from 23 to 38 dB L_{Aeq} (mean 32 dB, SD 3.7 dB).

Table II. Room acoustic and voice measurement data.

School type	Gender	Mean $L_{pZ, 1\ m}$ dB	Phonation %	T_{mf} (s)	UANL L_{Aeq} dB	UANL L_{A90} dB	Mean occupied noise level L_{Aeq} dB
Secondary	Female	57	22	1.0	28	25	63
Secondary	Male	62	16	0.4	23	20	60
Secondary	Male	60	18	0.3	24	23	60
Secondary	Female	66	13	0.9	27	23	64
Primary	Female	63	26	0.5	29	27	69
Primary	Female	72	28	0.6	37	37	69
Primary	Female	75	26	0.9	38	28	67
Primary	Female	65	23	0.9	32	31	63
Primary	Female	68	18	0.8	32	32	67
Primary	Male	64	13	1.0	30	29	66
Primary	Female	58	18	0.4	29	27	65
Primary	Female	71	18	0.4	30	26	64
Primary	Female	79	18	0.7	35	34	67
Primary	Male	61	22	0.8	37	33	63
Primary	Female	76	25	0.5	35	34	68
Primary	Female	75	26	1.1	29	29	71
Primary	Male	70	19	0.4	30	26	66
Primary	Female	78	31	0.4	26	25	68
Primary	Female	62	27	0.3	28	26	65
Primary	Male	63	15	0.7	28	26	67

The L_{A90} values are also shown in Table II for information, as these may better represent the underlying ambient noise levels in rooms.

There was a significant range of reverberation time values between the classrooms, with T_{mf} ranging from 0.3 to 1.1 seconds, with a mean value of 0.7 seconds (SD 0.24 s).

During teaching operations the occupied noise levels ranged from 60 to 71 dB L_{Aeq} with a mean value of 66 dB L_{Aeq}.

Thus, in terms of dBA, the UANL did not contribute numerically to the occupied dBA noise level, which was controlled by activity noise. However there remains the potential for ambient noise to have an influence on activity noise levels via the Lombard effect [6].

In terms of the teachers' voice parameters; the mean voice level was $L_{pZ, 1\ m}$ 67 dB (SD 6.7 dB) and ranged from 57 to 79 dB.

When considering voice level by gender, the male participants had a lower mean value of $L_{pZ,1\ m}$ 63 dB (SD 3.2 dB) than the female participants' mean value of $L_{pZ,1\ m}$ 69 dB (SD 7.0 dB). This is the opposite of the average voice levels in guidance documents [7] for the general population where males have higher voice levels at all vocal effort levels.

When considering voice levels by school type the secondary school participants had a lower mean voice level of $L_{pZ,1\ m}$ 61 dB (SD 3.3 dB) compared with the primary school participants' voice level of $L_{pZ,1\ m}$ 69 dB (SD 6.4 dB).

For the phonation percentage these were within the range of values found by other studies in the literature [8].

4. Analysis

The acoustic measurements showed that the classrooms ranged from those that complied with the contemporary acoustic requirements (see Table I), in some cases bettering the requirements, to those which did not meet the criteria.

Of the classrooms measured, two did not comply with the current new build standards for both unoccupied ambient noise levels (UANL) and reverberation time. Three of the classrooms had UANLs that exceeded the current criterion for new classrooms; all rooms complied with the UANL criterion for refurbished classrooms.

This is considered to give a good representation of the classroom types currently in use in England, and reflects the different environments in which teachers work.

The measured occupied noise levels were significantly above the unoccupied levels in terms of overall dBA values. However, the difference between occupied and unoccupied levels was less than 10 decibels in some frequency bands meaning there was potential for contributions from unoccupied noise sources to the overall, occupied noise levels, particularly at lower frequencies, which could influence teachers' voice parameters.

To further explore the relationships between voice and acoustic parameters independent t-tests and correlation analysis were undertaken. These identified a number of significant relationships between parameters. Where relationships have been found to exist, causality has not been established, but they suggest areas of interest for further research.

Due to the differences in the typical SF_0 values between the genders [9], data were analysed separately for male and female participants.

The highest correlation coefficients between voice levels and noise levels occurred for the UANLs in the 125 and 250 Hz L_{90} octave bands, as shown in Table III (significant correlations at the $p < 0.05$ level are shown in bold). The L_{90} UANL values tended to have a stronger correlation than the L_{eq} values. The L_{90} value is likely to be a better representation of the true UANL as it is not affected by short term noise events.

There were only significant correlations for the female participants, however for information the corresponding values for the male participants are included in Table III irrespective of significance.

In summary there were moderate positive correlations identified between voice levels and UANLs which were close to significant.

Table III. UANL and voice parameter correlations

UANL Parameter	Voice level mean $L_{pZ,\ 1\ m}$ dB			
	Male $n = 6$		Female $n = 14$	
	r	p	r	p
L_{eq} 125 Hz	0.45	0.38	0.47	0.09
L_{eq} 250 Hz	0.02	0.97	**0.56**	**0.04**
L_{90} 125 Hz	0.66	0.15	0.43	0.13
L_{90} 250 Hz	0.17	0.75	**0.61**	**0.02**

There was a significant correlation for female participants with the UANL values in the 250 Hz band which corresponds to the typical female SF_0 value [9]. There were indications of a similar effect in male participants at the lower 125 Hz band though the small sample size may have limited the significance.

The calculated Lombard effects [6] in these bands were higher for females compared with males and equate to the following mean voice level increases:

Females: 0.9 dB per dB increase in the UANL 250 Hz band for both L_{90} and L_{eq}.

Males: 0.3 dB per dB increase in the UANL 125 Hz band L_{eq} and 0.4 dB per dB for the 125 Hz L_{90}.

This indicates that the voice levels for female participants had a greater increase relative to UANL than the male participants in the octave bands related to the respective mean SF_0 values.

This indicates that low frequency UANL values may have an effect on the voice levels of teachers, though current school UANL criteria are expressed in dBA only and hence do not consider low frequencies.

There were moderate to strong positive correlations between voice levels and a number of occupied noise level parameters. These occupied noise level correlations may be a result of the teacher's voice level being a contributory component of the overall occupied noise level along with activity noise from children. The correlation for occupied L_{Aeq} was significant in the female participants ($r = 0.58$, $p = 0.03$) but not for the male participants ($r = 0.62$, $p = 0.19$). This would warrant further investigation with a larger sample size.

There were no significant correlations between reverberation times and associated room acoustic properties and voice parameters.

5. Discussion

The majority of the classrooms involved in this project complied with the current school acoustic standards given in BB93 (see Table I).
This should mean that they also meet the intended aims of the guidance in making classrooms safe spaces for teachers to speak in, as per the intentions of the SPRs and BB93.
However, the data showed that the mean voice levels of the teachers (67 dBZ at 1 m) were in the 'loud' category of guidance documents [10] and that the mean phonation percentage was also high at 21%.
This showed that the participants had a high vocal load even in classrooms compliant with current acoustic requirements and guidance.
The relationship between voice behaviour and parameters and voice problems is not definitive. However the risks of voice problems are considered to increase with vocal loading based on studies in the literature [11] and therefore high voice levels have been considered to place individuals at higher risk of vocal loading and voice problems.

6. Conclusions

The schools, classrooms and teachers that participated in the study were selected to be as representative as possible of the current teaching profession and conditions in England. The classrooms represented the full range from classrooms unchanged since their original construction in the 19th Century to those featuring modern constructions.
The analysis of the voice and acoustic data has indicated that noise intrusion into the classrooms from sources such as traffic and building services, which are under the remit of school design guidance, has a significant effect on teachers' voice levels when classrooms are in use. This study has also identified that in particular the teachers' voice levels were influenced by noise at low frequencies, the control of which is not specified in current guidance in England.
It has therefore been shown that the acoustic design of classrooms has the potential to affect the voice parameters of teachers and to therefore increase voice loading and the risks of voice problems. It is hoped that this study will assist in contributing to practical guidance for school design in how best to consider the voice ergonomics of teachers.
It is recommended that any future revision of the current acoustic standards in England should specify unoccupied ambient noise level criteria at low frequencies, specifically in the 125 and 250 Hz octave bands.

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