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Classroom acoustics for vocal health of elementary school teachers

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School teachers have an elevated risk of voice problems due to vocal demands in the workplace. ANSI SI2.60-2002 provides a standard for classroom acoustics, but it focuses primarily on students and unoccupied classroom settings. This presentation explores a preliminary study of six elementary school teachers that included measurements of architectural acoustics parameters and noise-levels of their classrooms, as well as their speech levels and fundamental frequencies over the course of a school day. The measurement methods and speech trends are discussed for the various cases, demonstrating that classroom acoustics standards may benefit from greater attention to teacher vocal health.

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INTRODUCTION

More than 18% of the 3 million primary and secondary school teachers in the US miss at least one day of work per year due to voice disorders (Smith, et al., 1997). Understanding the noise levels present in elementary school classrooms and their association with architectural acoustics measures may help focus improvements to classroom acoustics to benefit the teacher as well as the listening students. The study reported in this paper is an initial investigation of classroom acoustics from the teacher's perspective.

The current US standard on classroom acoustics, ANSI S12.60, has two points that will be considered in this study:

1. Unoccupied classroom noise levels must not exceed 35 dBA.
2. Unoccupied classroom reverberation time must not surpass 0.6 seconds in smaller classrooms or 0.7 seconds in larger rooms.

In addition to noise levels and reverberation times, this study considered several architectural acoustic parameters, including early decay time (EDT), speech transmission index (STI), and clarity for speech (C50). The reverberation time measurements were based on T20 calculations from impulse response measurements. The speech-to-noise ratio (SNR) was also calculated.

The Lombard effect is a well-documented speech effect in which a speaker involuntarily increases his or her vocal effort in response to an increase in background noise. This may be manifested through a change in fundamental frequency, speech level, or other measures (Lu and Cooke, 2008).

OBJECTIVES

The overall objective of this research was to better understand optimal classroom acoustics and noise conditions that promote improved vocal health for occupational voice users, such as teachers. Five elementary school teachers in the Provo, Utah area volunteered to participate in a preliminary study. Students from Brigham Young University (BYU) visited the classrooms to measure the classroom architectural acoustical parameters and speech and noise levels in order to assess their effects on teachers.

MEASUREMENTS AND RESULTS

Architectural

The student research team arrived at each classroom well before school started to set up for measurements. The intent was to disturb the classroom learning environment as little as possible while still collecting useful data. Seven microphones were hung from the ceiling and their positions were documented (see Figure 1). The microphones were calibrated using a GRAS 51AB calibrator. A dodecahedron loudspeaker was placed in two different locations in the room (see Figure 2). Consideration to the loudspeaker position was given to more closely place it in locations where the teacher would likely stand while teaching. Impulse response measurements were made using EASERA. A maximum-length-sequence (MLS) signal was used in each of the measurements, which were taken before school-age students arrived (unoccupied classroom) and again at the beginning of the school day, when all students were seated at their desks (occupied classroom).

Architectural acoustics parameters were calculated from the impulse response measurements. The results for the five classrooms are summarized in Table 1. As seen in the table, all of the measured classrooms met the ANSI standard on reverberation time. The STI and C50 results were also favorable. The T20 unoccupied values are green to show that they meet the ANSI criterion.

Color maps of several parameters calculated for a broadband frequency range are shown in Figure 3 to show their rough spatial distribution. As shown in Figure 4, reverberation time was also calculated over frequency, with additional attention to the frequencies most important for speech.

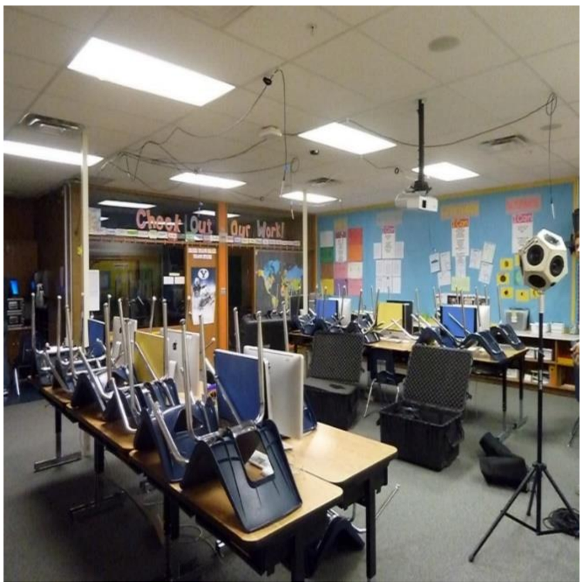

Figure 1. Microphones were hung from the ceiling in each of the classrooms. Also pictured is a dodecahedron loudspeaker used in the impulse response measurements.

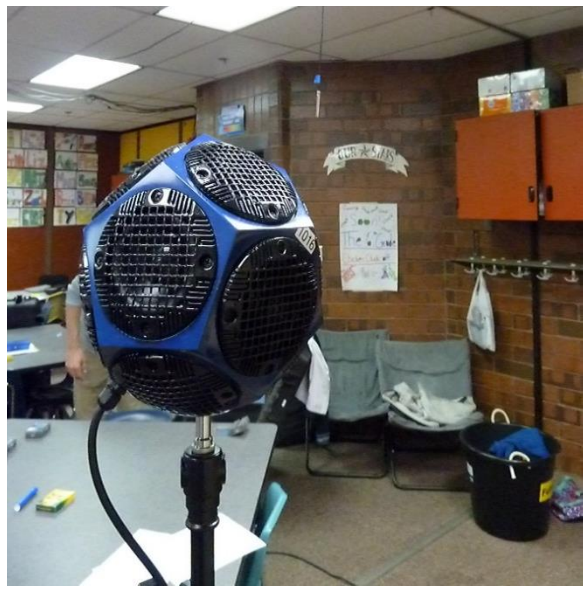

Figure 2. Another dodecahedron loudspeaker used in impulse response measurements in the classrooms.

Table 1. Summary of classroom architectural acoustical parameters.

Classroom #	T20 (s) Unoccupied	T20 (s) Occupied	EDT (s) Occupied	STI (%) Occupied	C50 (dB) Occupied
1	0.45	0.42	0.40	86	12.45
2	0.42	0.39	0.35	83	9.22
3	0.46	0.43	0.39	81	7.37
4	0.48	0.46	0.36	91	13.84
5	0.47	0.38	0.32	89	13.79

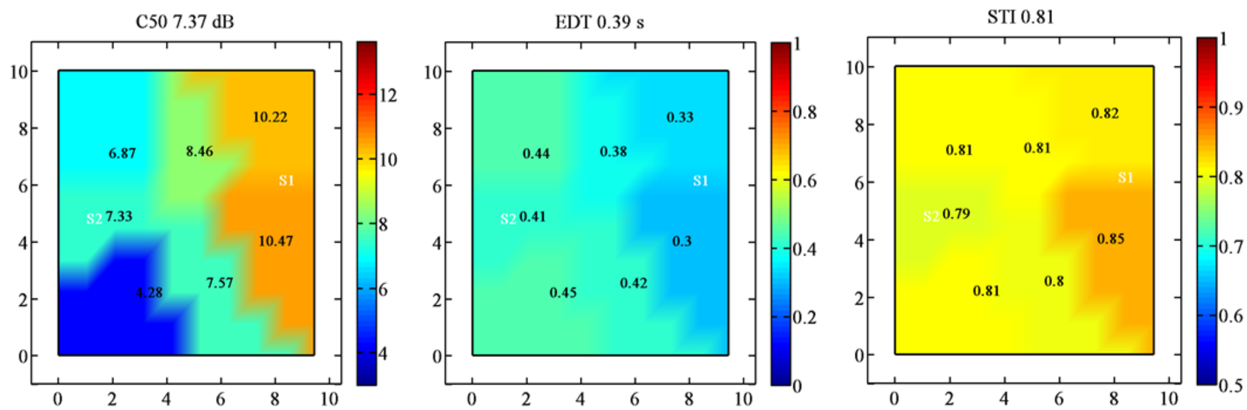

Figure 3. Spatial distribution of the architectural acoustical parameters in one of the measured classrooms. The x and y axes represent the dimensions of the classroom. The small black numbers represent the calculations at each of the microphone positions. The colors show interpolation and extrapolation between and beyond the microphone positions. The small white numbers represent the source positions during the measurements. The title of each graph identifies the parameter displayed and the average value for the entire room.

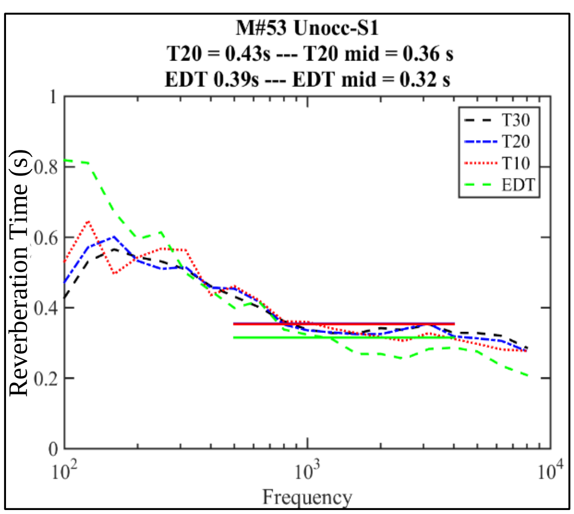

Figure 4. Reverberation time in one of the measured classrooms. The reverberation times at mid frequencies were of special interest, because of their importance for speech.

Noise

Noise measurements were made over the entire school day. The seven microphones used in the impulse response measurements were left hanging from the ceiling until the research team returned at the end of the school day to collect the equipment. The microphones were hung at a height to be unobtrusive to students' learning, and out of their reach. They were connected to a digital audio workstation for recording (see Figure 5). Equipment was set in a corner of the room, out of the way of the teacher and students. To protect student privacy, all recordings were converted to A-weighted levels, so no information about what was spoken or what specifically occurred in the classroom was retained. The six- to seven-hour recordings from each school day were separated into 30-second segments, to enable more efficient data storage and analysis.

Noise levels and calculated Leqs were plotted against time for each of the classrooms. Figure 6 shows an example of one of these plots, with notes on what occurred in the classroom at a few points in time. Table 2 summarizes the lowest and highest levels measured in each classroom. Two of the classrooms in our measurements did not meet the ANSI standard for unoccupied classroom background noise levels; their peak levels are indicated in red.

Figure 5. Microphones connected to the digital audio workstation.

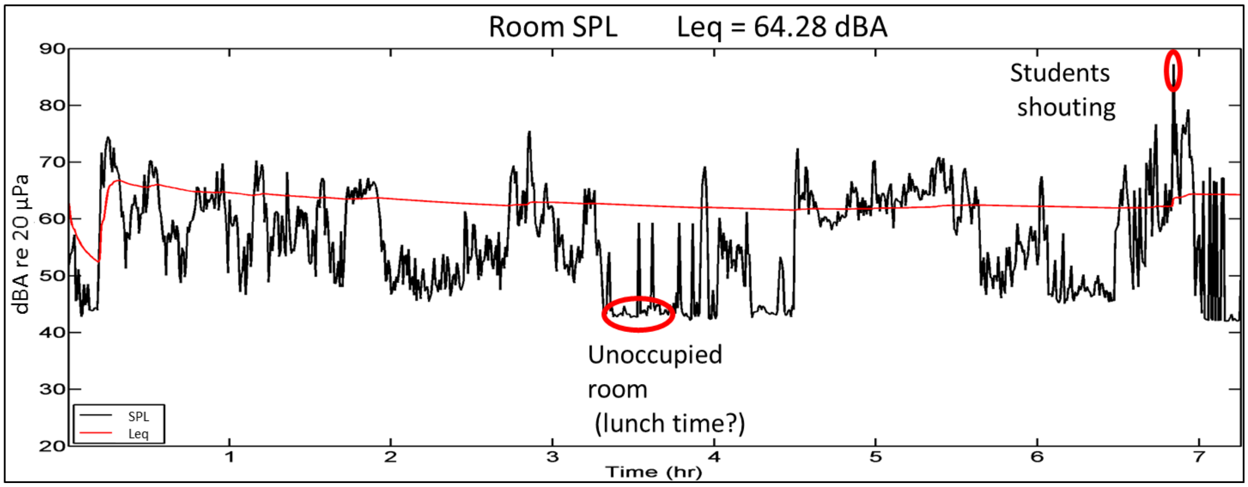

Figure 6. Time-dependent noise levels in one of the classrooms over time.

Table 2. Minimum and maximum noise levels in the classrooms. Red indicates the observed minimum levels which did not meet the ANSI standard.

Classroom	Leq (dBA)	Time (hours)	Min (dBA)	Time (hours)	Max (dBA)
1	58.42	5.67	39.69	6.33	68.88
2	58.86	1.58	34.09	2.5	65.44
3	64.28	7.25	41.98	6.92	93.90
4	71.71	4.67	29.9	3.92	71.6
5	63.43	2.83	31.24	6.17	76.45

Speech

The teachers participating in this study wore a Sonvox Voxlog collar during the school day (see Figure 7). This collar, worn on the neck, contains both an accelerometer and a microphone. It was placed on the teacher's neck to be comfortable and adequately collect vibration data. The collar output was connected to a Zoom H5 personal recorder. A method for absolutely calibrating the accelerometer and microphone in the collar has not yet been developed, so only relative values are reported in the following results. Similarly to the noise data, the speech data were segmented into 30-second blocks.

Speech and noise were identified and separated using the accelerometer signal. If the accelerometer signal was above a certain threshold within a 30-second block, it was identified as speech. The microphone signal for the time the accelerometer was above the threshold was spliced together and identified as speech. The microphone signal for the time the accelerometer was below the threshold was spliced together and identified as noise. An example of this is shown in Figure 8. For all of the 30-second blocks collected over the school day, only the blocks that contained between 5 and 25 seconds of speech were used in the following analysis.

The speech signal was analyzed using Praat software. The average fundamental frequency volume (level) of the speech for each 30-second block was calculated. Using the speech levels from the teacher's microphone and the noise levels during the times the teacher was not speaking, speech-to-noise levels were calculated. Figure 9 shows two speech-to-noise ratios over time when the teacher was not speaking. One was calculated using the noise part of the signal from the teacher's microphone, and the other was calculated using the room microphone noise levels. Significant variations in speech-to-noise levels over the entire school day were apparent, but no trends were immediately clear. Similarly, fundamental frequencies were plotted over time, but again no trends were observed. An example is shown in Figure 10.

Figure 7. Sonvox VoxLog collar with accelerometer and microphone.

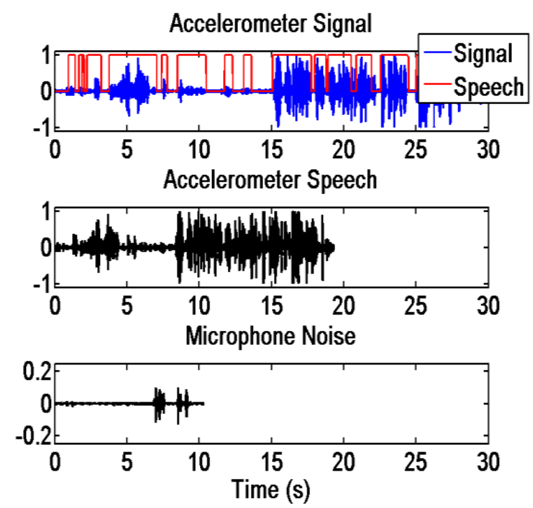

Figure 8. Separation and splicing of speech and noise using the accelerometer.

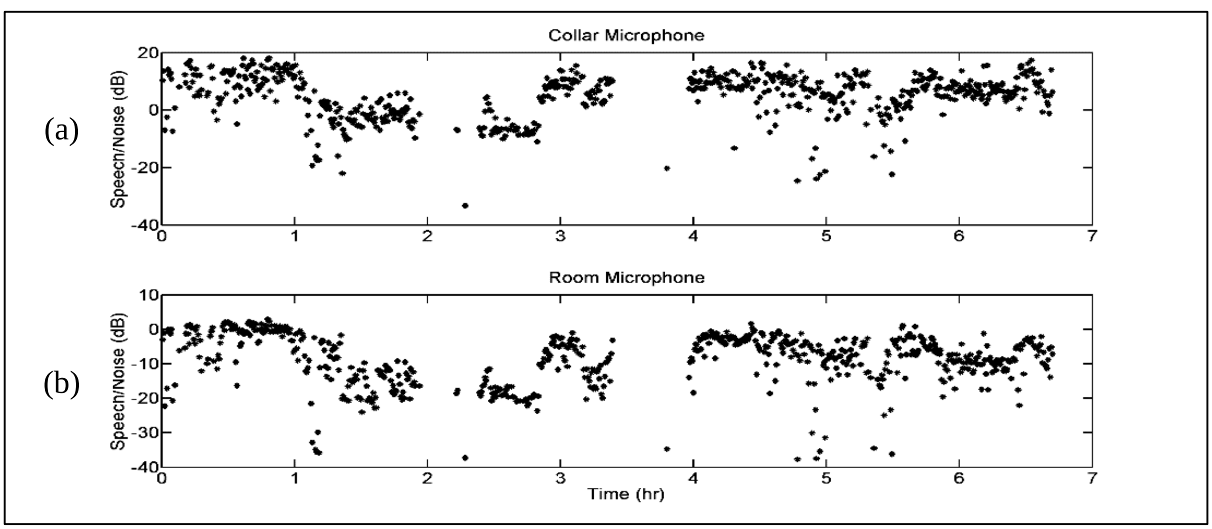

Figure 9. Examples of speech-to-noise levels over time. Plot (a) shows speech-to-noise levels calculated using the collar microphone. Plot (b) shows speech-to-noise levels calculated using the room microphones.

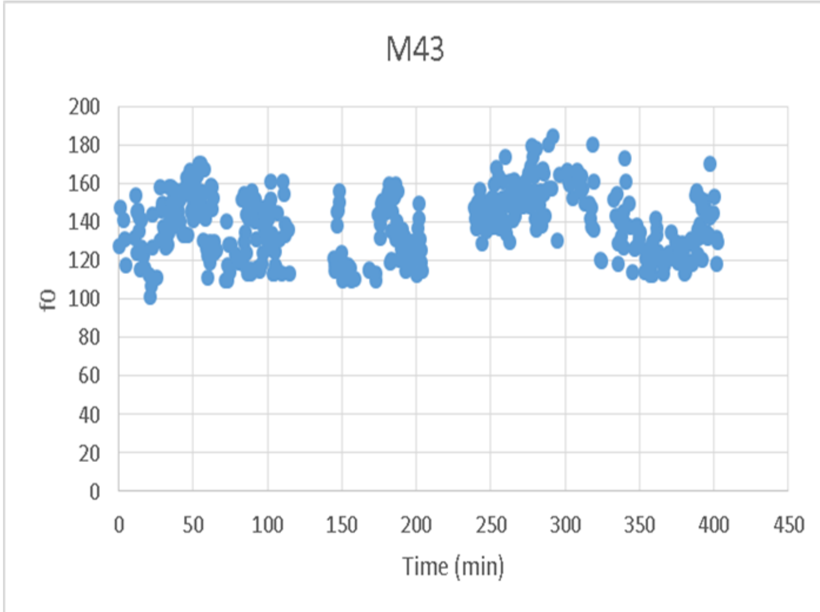

Figure 10. Example of fundamental frequency over time.

Using the work of Bottalico and Astolfi (Bottalico and Astolfi, 2012) as a guide, increases in fundamental frequency along with speech level as background noise level increased, were calculated. They found that the speech level increased 0.72 dB per 1dB increase in background noise, and that fundamental frequency increased by 1 Hz per 1 dB increase in background noise. While the current study did not have a large sample size, the speech of the measured teachers appeared to follow the same trends. Figure 11 shows a speech-to-noise trend line drawn for one teacher. Figure 12 shows the trend lines for all the teachers. Figure 13 shows a fundamental frequency-to-noise trend line drawn for one teacher. Figure 14 shows the trend lines for all the teachers. Table 3 lists the slope values for the trend lines for both speech-to-noise and frequency-to-noise.

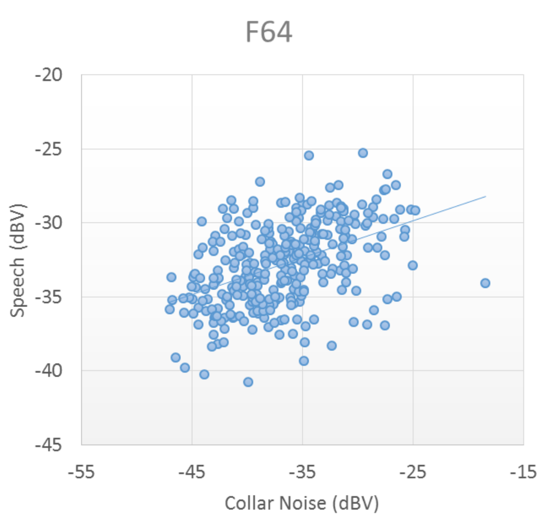

Figure 11. Speech-to-noise for an example teacher.

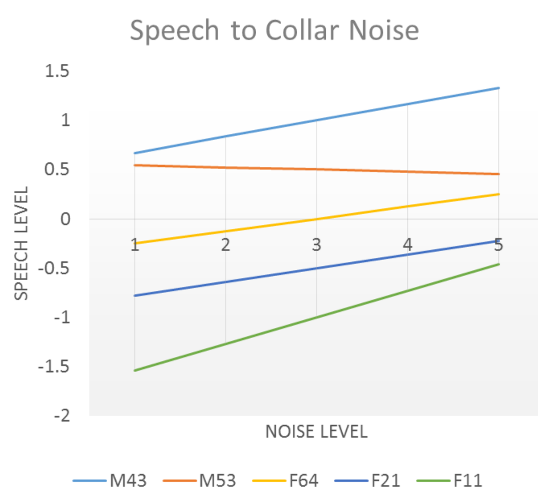

Figure 12. Speech-to-noise slopes for all measured teachers. Here, M represents Male and F represents Female. The other numbers identify the subjects and their schools.

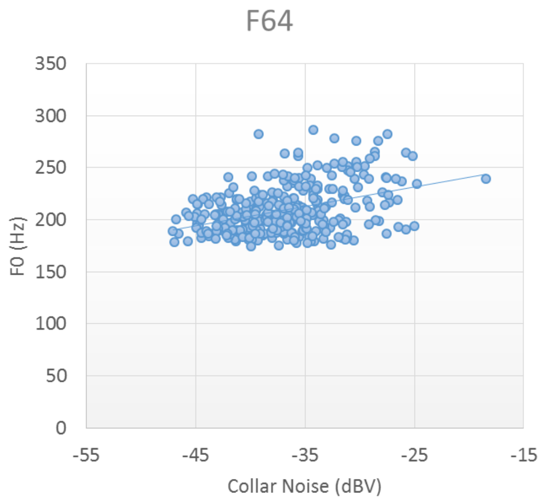

Figure 13. Fundamental frequency by noise level for an example teacher.

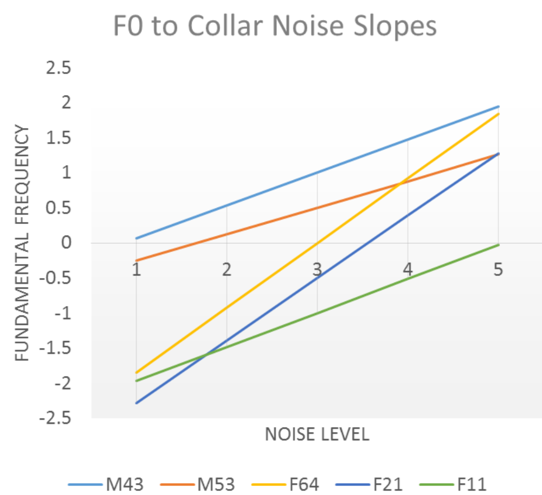

Figure 14. Fundamental frequency slopes for all measured teachers.

Table 3. Speech-to-Noise and Frequency-to-Noise slopes for all measured teachers.

Classroom	Subject	Speech-to-Noise Slope (dB/dB)	Frequency-to-Noise Slope (Hz/dB)
1	F11	0.92	0.97
2	F21	0.68	1.78
3	M43	0.33	0.94
4	M53	-0.05	0.76
5	F64	0.60	1.84

DISCUSSION

Our measurements of the classroom architectural acoustical parameters revealed that, in general, the rooms met the standards in ANSI S12.60. All of the classrooms were very similar, with good STI and Clarity. We found a wide variation in noise levels over the course of a school day, which is to be expected due to the many and varied activities that occur in a classroom. The unoccupied classroom noise levels we measured did not meet the ANSI standard in every case. It could be that the classroom was never fully unoccupied during the school day and the minimum value we found was not the true unoccupied background noise level.

Despite our small sample size, the speech trends we observed generally agree with those found elsewhere. This indicates that the teachers we measured may have exhibited vocal efforts similar to those of other professional voice users. One male teacher actually had a very small decrease in speech level with an increase in background level when the data from the entire school day was analyzed. Our small sample size inhibits general conclusions, but it appears that the female subjects had higher speech-to-noise slopes than did the male subjects. This implies that the female subjects increased their speech level more per dB increase in background noise than did the male subjects. No gender differences are found in the frequency-to-noise slopes, although it is noted that two female subjects increased their fundamental frequencies more than the expected one Hz per dB increase of background noise.

There is still much work to do in the measurement methods. The Sonvox collar is a relatively new device, and consistency in its placement on different participants was a challenge. Despite the difficulties in the initial setup, the collar collected reliable data during the course of the school day measurements. A method for calibrating the accelerometer and microphone on the Sonvox collar has been developed and will be applied to future measurements. Time synchronization between the teacher's personal recorder and the data recorded by the room microphones was also an issue. This could be remedied by using a wireless transmitter with the collar, so all data is recorded on the same digital audio interface. This would also eliminate inadvertent changes in the gain knobs on the personal recorder.

The noise conditions could be further explored by categorizing the data by activity in the classroom (quiet group work, uncontrolled yelling, teacher-led instruction, etc.). Then trends in the teacher's vocal effort (speech level or fundamental frequency) could be analyzed for the different noise situations encountered in the classroom.

CONCLUSIONS

This study has sought to investigate classroom acoustics from the teacher's perspective. In particular, a new method for measuring teacher vocal effort in real-time classroom environments has been developed and implemented in this initial study. This method could prove invaluable to further research in professional vocal users' vocal health because it is performed in real environments, not in a laboratory. The method also shows real-time reactions to changes in the environment. In essence, it shows real vocal effort in real situations.

The results of this initial study indicate that the classrooms measured generally meet the current ANSI standard for classroom reverberation times, but do not all meet the noise requirement. The analysis of this study reveals that background noise levels do affect teacher vocal effort. The sources of background noise vary from students to furniture and classroom appliances. The vocal effort of the teachers generally follows trends previously seen in speech-to-noise increases and fundamental frequency-to-noise increases.

Teacher vocal health should be given strong consideration when developing new classroom standards. Some consideration must also be given to the noise levels of an occupied classroom, including noise from students and furniture, over the course of a school day.

ACKNOWLEDGEMENTS

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REFERENCES

ANSI/ASA S12.60 american national standard acoustical performance criteria, design requirements, and guidelines for schools. Edition 10, Acoustical Society of America (ASA)**:** 46.

Bottalico, P. and Astolfi, A. (2012). Investigations into vocal doses and parameters pertaining to primary school teachers in classrooms. The Journal of the Acoustical Society of America. **131:** 2817.

Durup, N., et al. (2013). Vocal strain in uk teachers: An investigation into the acoustic causes and cures. The Journal of the Acoustical Society of America. **133:** 3553.

Lu, Y. and Cooke, M. (2008). Lombard speech: Effects of task and noise type. The Journal of the Acoustical Society of America. **123:** 3072.

Smith, E., et al. (1997). Frequency and effects of teachers' voice problems. Journal of Voice. **11:** 81.

Smith, E., et al. (1998). Frequency of voice problems among teachers and other occupations. Journal of Voice. **12:** 480.

Titze, I. R., et al. (1997). Populations in the u.S. Workforce who rely on voice as a primary tool of trade: A preliminary report. Journal of Voice. **11:** 254.