Evaluation of acoustical conditions for speech communication in active elementary school classrooms

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Abstract

Detailed acoustical measurements were made in 41 active elementary school classrooms near Ottawa, Canada to obtain more representative and more accurate indications of the acoustical quality of conditions for speech communication during actual teaching activities. This study found: a mean speech-to-noise ratio in active classrooms of 11dBA, reverberation times from 0.3 to 0.6 s that were not related to noise levels, and the effects of children on acoustical conditions.

1. Introduction

41 classrooms were investigated including 16 grade 1 (G1), 12 grade 3 (G3) and 13 grade 6 (G6). On average 21 children were in each classroom during measurements. The average number of children in classrooms of G1, G3, and G6 were 19, 20, and 22 respectively. Seven of 41 classrooms were initially open-plan classrooms and had unique shapes. The average dimensions of the 34 rectangular classrooms were 9.4m x 7.6m x 2.8m (V= 197m^3, S=236m^2).

2. Room acoustics measures in classrooms

2.1. Methods

Room acoustics quantities were obtained from impulse response measurements in occupied and unoccupied classrooms. A sine sweep signal (covering 6 octave bands from 125Hz to 4kHz) was used to obtain the impulse responses and was radiated into the classroom from a small loudspeaker with directional properties similar to a human talker. The speaker was set 1.5 m above the floor at the front of the room where the teacher would normally stand. Sound level meters with digital wireless transmitters were located 1.2 m above the floor at 4 locations in each classroom. Room acoustics measurements were obtained at 4 locations in 38 of the 41 classrooms.

2.2. Results

Table 1 shows reverberation time and early-to-late energy ratios (C_{50}) for both occupied and unoccupied classrooms to determine the average effects of children on acoustical condition in the classrooms.

For the unoccupied classrooms, mid-frequency reverberation times varied from 0.3 to 0.7 s with a mean of 0.45s. When the classrooms were occupied, reverberation times were decreased by approximately 10% as shown in Fig.1. Early decay times also indicated similar results, but early decay times sometimes exceeded reverberation times due to strong flutter echoes observed in some classrooms.

The mean absorption power was found to be 0.35m^2/person from the difference of A-weighted reverberation times. Furthermore, C_{50} increased by 1.34dBA when the rooms were occupied as shown in Fig.2. The improvement consisted of 0.49dBA (S.D.= 0.54) decrease of early reflection energy (including direct sound) and 1.84dBA (S.D. = 0.79) decrease of late arriving energy.

The authors have previously demonstrated the importance of early reflections [1] and used the early reflection benefit (*ERB*) to assess their effectiveness. *ERB*, the relative increase in early arriving sound within 5 to 50 ms relative to the direct sound energy, increases with distance from a sound source by up to 5dB in Fig. 3. The *ERB* values did not correlate with reverberation times. However, late arriving energies, more than 50 ms after the direct sound (measured relative to the direct sound energy), were correlated with reverberation times as shown in Fig. 4. These results suggest that controlling reverberation time in the design process only relates to late arriving energy and early reflections should be considered separately.

*Table 1: Mean r*everberation times and early-to-late arriving energy ratios (C_{50}) measured in occupied and unoccupied classrooms.

Oct. band center frequency, Hz	125	250	500	1k	2k	4k	A-weighted
Occupied							
Mean rev. time,s	0.58	0.51	0.45	0.40	0.38	0.39	0.41
S.D.	0.14	0.09	0.10	0.11	0.09	0.08	0.09
Mean C50, dB	5.34	6.39	7.98	9.75	11.12	11.46	10.49
S.D.	3.55	2.76	2.53	3.00	3.09	2.83	2.68
Unoccupied							
Mean rev. time,s	0.61	0.53	0.48	0.45	0.43	0.43	0.45
S.D.	0.15	0.10	0.11	0.12	0.12	0.11	0.11
Mean C50, dB	5.20	6.01	7.37	8.32	9.58	9.87	9.13
S.D.	3.71	2.59	2.36	2.90	3.07	2.70	2.63

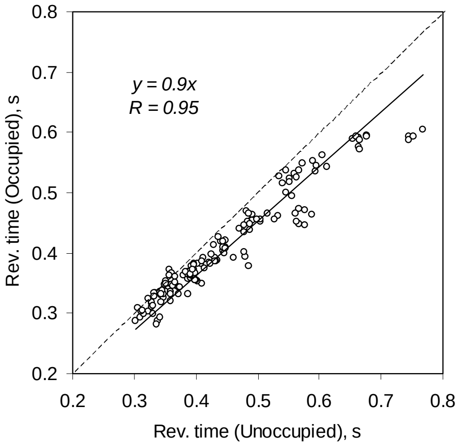

Figure 1: Relation between measured reverberation times in occupied and unoccupied classrooms.

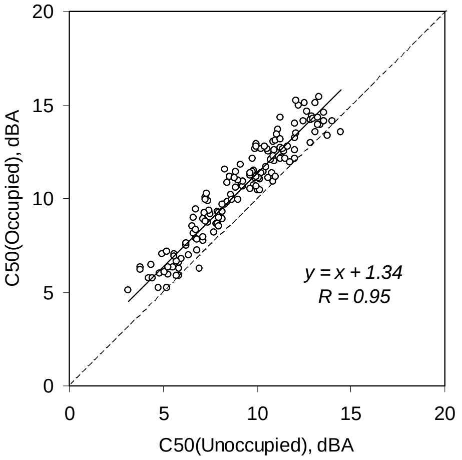

Figure 2: Relation between measured C_{50} values in occupied and unoccupied classrooms.

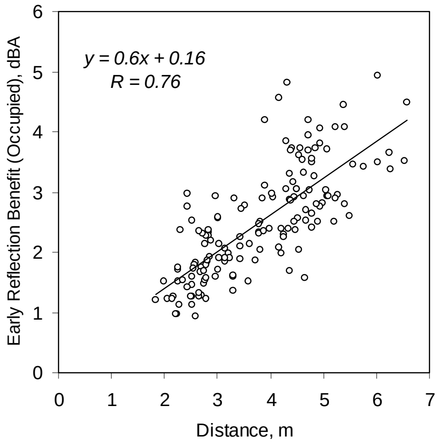

Figure 3: Early Reflection Benefit as a function of distance from the sound source.

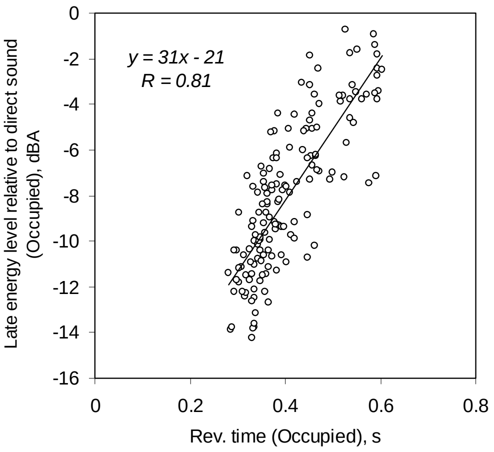

Figure 4: Relation between reverberation times and late energy levels (relative to the direct sound) in occupied classrooms.

3. Speech and noise level measurement during active classes

It is very important to know the levels of teachers' voices and classroom noises during actual teaching activity. Table 2 provides background noise levels measured in terms of L_{eq} values during impulse response measurements in quiet (no student activity) occupied and unoccupied conditions. Mean noise levels in the unoccupied classroom were more than the 35dBA recommended by ANSI [2].

Table 2: Background noise L_{eq} values measured in quiet occupied and unoccupied classrooms

Oct. band center frequency, Hz	125	250	500	1k	2k	4k	A-weighted
Occupied							
Mean	46.6	43.9	41.5	38.4	35.3	31.6	44.5
S.D.	6.2	4.0	3.9	4.1	3.7	3.3	3.7
Unoccupied							
Mean	46.0	42.1	39.6	36.2	31.6	26.7	42.1
S.D.	5.6	4.3	4.6	4.7	4.5	3.6	4.2

3.1. Methods

Recorded speech and noise levels were determined at 200ms intervals. Distributions of these levels were used to estimate separate speech and noise levels as suggested by Hodgson [3]. Two normal distributions were fitted to each histogram of A-weighted levels. One distribution identified the noise and the other the teachers' voice levels. Hodgson describes using 3 distributions (speech, ventilation noise, and student activity noise) for university classroom measurements, but only two distributions were used in this study because the main purpose was to measure teachers' voice levels relative to all other sounds. In addition, the activity noises of children in elementary schools have a wide range of levels and are difficult to differentiate with this technique. Fig. 5. describes the fitting of normal distributions to speech and noise levels.

This technique could not be applied to seven open-plan classrooms. Because of poor isolation between adjacent classrooms, wanted and unwanted speech sounds could not be separated using this technique. These analyses were completed for 28 of the enclosed rectangular classrooms.

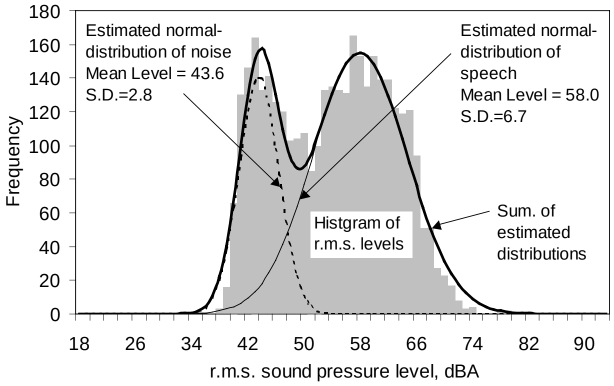

Figure 5: Example of histogram of r.m.s. sound pressure level with 200ms of time window obtained by an active class recording at one microphone position.

3.2. Results

Fig. 6 presents distributions of the average speech and noise levels for 118 cases (4 points x 28 rooms). Mean speech and noise levels were 59.5dBA and 49.1dBA respectively. The corresponding free field speech level at 1m from talker was estimated to be 68.8dBA employing a 2.73dBA average direct-to-reflected sound ratio from impulse responses and an average distance of 3.75m between sound source and listening points. For the distribution of speech levels 1m from the talker, 16% were between “Normal” and “Raised”, 52% between “Raised” and “Loud”, and 29% between “Loud” and “Shout” for Pearson’s descriptions [4].

The distribution of mean speech–to-noise ratios in all classrooms are shown in Fig.7. These ignore variations with time within each recording. This estimation suggests that only 2% of the classes satisfy the S/N ≥ 15dBA requirement for 12-13 year old children to get near perfect word recognition scores [5]. Detailed discussion of speech intelligibility scores is in another paper [6].

Fig. 8 shows that mean speech and noise levels are well correlated (correlation coefficient: R=0.82). The increasing teacher voice levels with increasing noise levels shown here is an example of the Lombard effect. Lane and Tranel found a 0.5dB increase of speech level per 1dB increase of noise level [7]. Fig. 8 shows a 0.82dB increase of speech level per 1dB increase of noise level.

From the speech and noise level distributions in Fig. 6 one could estimate a mean S/N of 10.7dBA with S.D. of 9.3 by ignoring the Lombard Effect and assuming speech and noise levels are not related. The actual variance of *S/N* in active classrooms is expected to be between the 2.55 in Fig.7 and 9.3.

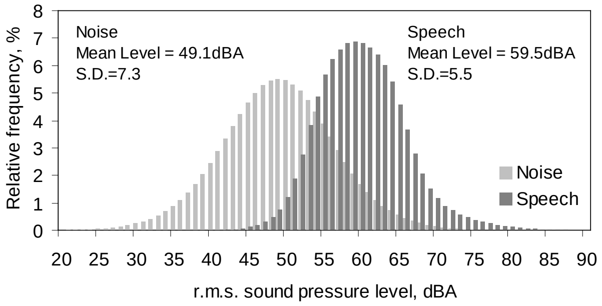

Figure 6: Relative frequency distribution of speech and noise level on the average of 28 classes recording.

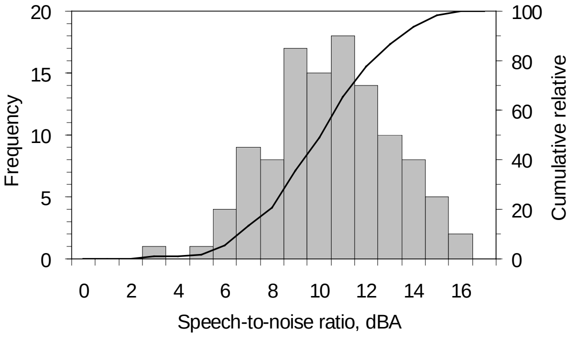

Figure 7: Frequency distribution of speech-to-noise ratio and its cumulative relative frequency sum up all of mean S/N measured in each measurement point (N=118). Mean S/N of all classrooms is 11dBA(S.D.=2.55).

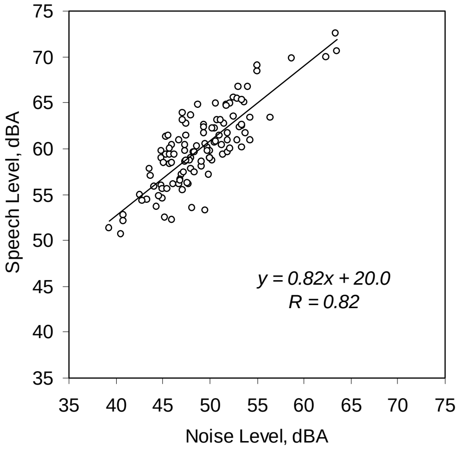

Figure 8: Relation between mean speech level and mean noise level in 28 classrooms obtained with statistical distribution technique

4. Discussion

Measured speech levels of teachers during active classes did not correlate significantly with *ERB* (*R*=0.15) nor with C_{50}(*R*=0.16). Speech levels were only slightly related to reverberation times (*R*=0.41) because of increased late arriving energy. Similarly, noise levels were not related to *ERB*, C_{50}, or reverberation time. Even though very short reverberation times are sometimes recommended [8] to control noise levels, this study suggests that values between 0.3 and 0.6s have no significant effect on noise levels. That is, adding absorption would not be expected to reduce these noise levels. As previously discussed, the beneficial effect of early reflections could improve *S/N* by up to 5dB, but adding absorption could reduce all reflections and educe this benefit.

Fig. 9 shows the relation between noise levels in active classrooms and those in quiet occupied conditions. In active classrooms, children generated increases of up to 10dBA or more in noise levels (5dB on average) except for one classroom (4 points) where noise levels actually decreased. It is very important to reduce noise sources caused by children's activities.

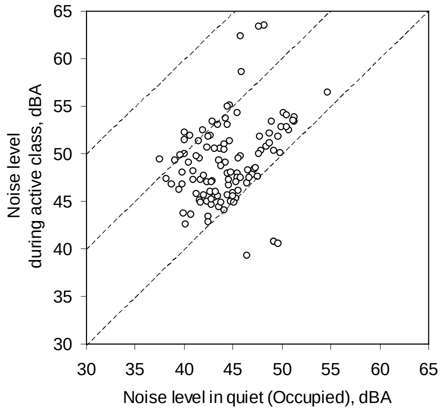

Figure 9: Relation of noise level between during active class and in quiet condition.

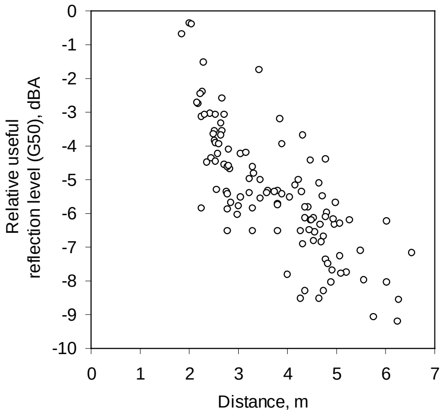

Figure 10: Relation between distance from sound source and relative useful energy (direct + early reflections) in occupied classrooms.

Fig.10 shows how useful early-reflection energy, including direct sound, decreases with distance from the source. These data include not only the effect of distance but also directivity of sound source. Fig. 10 shows that in spite of the increased benefits of early reflections, speech levels are much reduced at the rear of the classrooms.

5. Conclusions

In classrooms, noise control is the most important issue for achieving acceptable S/N values and especially so for children seated far from teacher. Student activity is seen to be the dominant noise source, increasing average noise levels by up to 10 dBA during teaching activities. However, there was no evidence that added absorption would decrease these noise levels. The measured noise levels in occupied classrooms are presumably largely due to the direct sounds from nearby student activity and can only be controlled at the source. Teachers' voice levels were higher than expected and the average vocal effort corresponds to louder than Pearson's "Raised" voice level. There is clear evidence that teachers increase their voice level to overcome ambient noise. In these classrooms, effective speech levels can be enhanced by up to 5 dB by sufficient early reflection energy. The results give a better understanding of the inter-relation of various acoustical parameters in classrooms. A second paper will present speech recognition scores in these classrooms [6].

6. References

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