Background Noise Levels and Reverberation Times in Old and New Elementary School Classrooms

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The adequacy of the acoustic environment of classrooms is an important factor in a child's ability to listen and learn. Undesirable noise and reverberation can affect the achievement and educational performance of children, both those with normal and impaired hearing. The purpose of this study was to evaluate the acoustical conditions of old and new elementary school classrooms. Results were compared to the American National Standards Institute standard for acoustical characteristics of classrooms (ANSI S12.60-2002). Results indicated that neither new nor old classrooms for children with normal hearing were in compliance with the ANSI classroom background noise standard but all classrooms met the minimum reverberation criteria.

Introduction

The two principle factors that degrade the acoustic quality of learning environments are background noise and reverberation. Background noise commonly refers to any undesired sound that impedes what a child needs or wants to hear (Boothroyd, 2005). Examples of background noise in learning environments include external noise such as outdoor traffic noise, noise from halls and other adjacent rooms, heating, ventilating and air-conditioning (HVAC) systems, as well as noise generated by the students themselves. Reverberation refers to the persistence or prolongation of sound within a space (Knecht, Nelson, Whitelaw & Feth, 2002). In rooms with excessive reverberation, speech signals are delayed and can overlap the direct sound – sound coming from the speaker – which often masks the message of the speaker. Research has shown that the reverberation and background noise levels of classrooms are frequently too high for optimum speech recognition by children to occur (Crandell, Smaldino & Flexer, 2005; Yacullo & Hawkins, 1987; Gelfand & Silman, 1979; Nabelek & Pickett, 1974) and therefore can interfere with the child's ability to learn. Poor acoustics can be detrimental to all children. This includes those with normal hearing, mild hearing losses, children with hearing aids or assistive devices, children with learning disabilities, children for whom English is a second language, as well as those with temporary hearing loss due to ear infections (Crandell et al., 2005).

In 1995, the American Speech Language Hearing Association (ASHA) established guidelines for acceptable background noise and reverberation within classrooms; however no empirical evidence exists indicating that these guidelines were ever implemented in school settings. In 2002, the American National Standards Institute (ANSI) established a voluntary standard for acceptable acoustic conditions within classrooms. This standard was created so that schools would consider building acoustics and the generated criteria for acceptable acoustical measures during construction and remodeling of schools. Currently, standards for classroom acoustics have not yet been mandated by law, which has made compliance infrequent and inconsistent. As new schools are designed and older schools remodeled, school districts are not legally required to abide by the ANSI standard or ASHA acoustical guidelines (ASHA, 2005).

Due to lack of compliance with the ANSI standard or the ASHA guidelines for desirable classroom acoustics, acoustical conditions in U.S. classrooms are highly variable. Studies have documented that reverberation times can vary from 0.3 seconds to greater than 1.5 seconds (Crandell & Bess, 1986; Finitzo-Hieber & Tillman, 1978; Pekkarinen & Viljanen, 1991), and background noise levels vary from 34-70 dBA for "typical" unoccupied classrooms in the United States (Knecht et al., 2002). Knecht et al. (2002) measured reverberation times and background noise levels in 32 unoccupied elementary school classrooms and compared the results to the ANSI S12.60-2002 standard. Results from their study indicated that most of the classrooms studied were not in compliance with the ANSI noise and reverberation standard. However, the study did not directly compare the results between older and newer classrooms to determine if there was a correlation between the age of the building, the acoustical environment and implementation of the ANSI standard.

The effects of poor acoustics in the classroom setting have been well documented in the literature. Yacullo and Hawkins (1987) found that children with normal hearing demonstrated reduced speech recognition with increased background noise and reverberation times. According to the ANSI standard, the recommended reverberation time that maximizes speech intelligibility is between 0.6-0.7 seconds and recommended background noise levels in occupied classrooms are below 35 dBA(ANSI, 2002). Nabelek and Pickett (1974) studied the influence of noise and reverberation on monaural and binaural reception of consonants. Results from their study demonstrate that children with hearing aids experience significantly greater difficulty recognizing speech in the presence of reverberation and background noise. Although all testing was completed in simulated environments where reverberation and background noise were alterable, the implications for the classroom environment are significant, especially for deaf and hard of hearing (DHH) children. As indicated by Jerger, Martin, Pearson, & Dinh (1995) degraded or impoverished stimuli may often be more difficult to remember, require more time and effort to process and may directly affect a child's ability to sustain voluntary attention. Jamieson, Kranjc, Yu & Hodgetts (2004) examined the ability of young children aged five to eight to understand speech (i.e., monosyllables, spondees, trochees, and trisyllables) when listening in a background of real-life classroom noise. Results showed that children in kindergarten and grade 1 had much more difficulty than older children, although all children had some difficulty understanding speech when the noise was at levels found in most classrooms (i.e., 65 dBA). The results from the Jamieson et al. study suggest that the youngest children in the school system, whose classrooms often tend to be the noisiest, are the most susceptible to the effects of excessive background noise.

Although the literature reports evidence of the detrimental impact poor classroom acoustics have on children, there is still no mandate that classrooms abide by nationally recognized standards. The ANSI standard is "strictly voluntary" (ANSI, S12.60-2002) and, consequently, often ignored. Bistafa and Bradley (2000) utilized analytical formulas for various speech intelligibility metrics (i.e., Speech Transmission Index, Articulation Index) to determine what conditions of noise and reverberation provide the greatest degree of speech understanding in classrooms. Results from their study suggested that in order to achieve 100% speech intelligibility in quiet classrooms, the reverberation time should actually be between 0.4 and 0.5 seconds. In addition, the same authors recommended that the ideal maximum background noise level for classrooms is 25 dB less than the voice level at 1 meter in front of the talker. This criterion is even more stringent than that suggested by the ANSI S12.60-2002 standard. However, Bistafa and Bradley suggested that these "ideal" conditions for reverberation and background noise levels would result in a classroom signal-to-noise ratio of more than +15 dB.

As older schools are renovated and new schools are being built, it is critical that the acoustical design of the classroom be considered in order to optimize the learning environment for children. Unfortunately, schools built after the development of the ASHA and ANSI acoustical documents still fail to follow acoustic guidelines in the classrooms (Knecht et al, 2002). For both the parents and professionals who advocate in favor of a law that would govern the acoustical conditions in the classrooms (www.parentsvoice.org), it is important to know if schools follow the voluntary measures established by ANSI and ASHA. The purpose of this study was to determine whether or not classroom acoustics are better in newly constructed and/or renovated elementary school classrooms compared to older classrooms based upon the ANSI S12.60-2002 standard established for schools.

Methods

Acoustic measurements were taken in thirty-six unoccupied elementary school classrooms located in nine school buildings in Chicago, and public schools in Wilmette, Frmont, Woodland, Wood Dale, and Kaneland, Illinois. Both urban and suburban schools were included and the sample is believed to be representative of the schools in and around a large metropolitan area. Sixteen of the thirty-six classrooms were considered to be "new" because they were built after 2002. Twenty of the thirty-six were considered to be "old" because they were in schools built prior to 1960. Table 1 shows the year each school was built. The dimensions of the unoccupied classrooms were measured and volumes calculated. These volumes are shown in Table 1.

All of the "new" classrooms and nearly all of the "old" classrooms were carpeted, had acoustic ceiling tiles and had some sort of absorptive materials covering much of the walls. The performance levels of these materials were unknown. The "old" classrooms all had window air conditioners or wall units for heating, ventilation and air conditioning (HVAC). The "new" classrooms typically had ducted central air conditioning units and many had ceiling fans. Of the thirty-six classrooms, four "old" and four "new" were used specifically as classrooms for DHH children. Each of the 8 rooms was carpeted, and had acoustic ceiling tiles and cork or some other absorptive materials in place. In addition, special noise reduction provisions were made in these DHH classrooms ranging from ducted HVAC systems to the use of ceiling fans for air circulation. For all rooms, the HVAC system, fans and lighting operated at their typical settings and equipment, such as computers, was turned off. The location of windows and doors were noted, as was the apparent composition of ceiling and wall materials. The rooms were believed to be representative of typical classrooms in the schools evaluated.

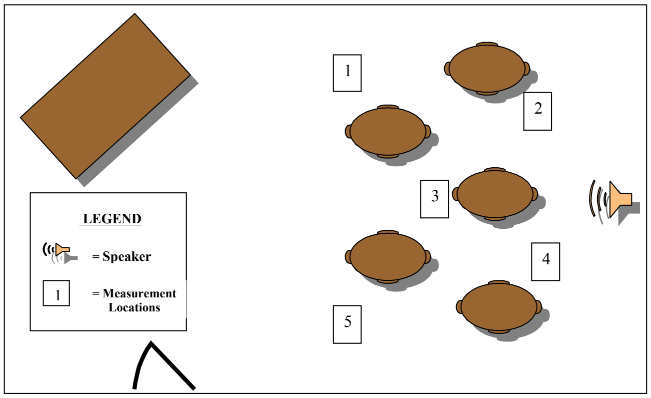
Background noise and reverberation acoustic measurements were conducted according to the ANSI S12.60-2002 procedures with some modifications. A Quest Technologies 2900 Integrating sound level meter (SLM) set at the A-weighting and fast response was used to measure the background noise at five different locations in the classroom in and around the students' desks. The SLM was positioned at 4 feet above the floor at each measurement location to simulate the position of a student's head when seated at a desk. The results of the five measurements were averaged and resulted in a single number representing the background noise level. A Quest Technologies OB-100 octave band filter was used in conjunction with the SLM to obtain the octave band measurements (63-8000 Hz) of the noise at each of the five measurement locations. These were averaged and used to determine

Old Classrooms	Year Built	Room Volume (ft^3)
1a	1949	8540
1b	1949	8540
1c	1949	8135
1d	1949	8284
2a	1958	8581
2b	1958	8390
2c	1958	8576
2d	1958	8691
3a	1942	8374
3b	1942	9494
3c	1942	7884
3d	1942	8196
4a	1952	7735
4b	1952	7850
4c	1952	7575
4d	1952	7630
5a	1917	5146
5b	1917	6153
5c	1917	6792
5d	1917	6792

New Classrooms	Year Built	Room Volume (ft^3)
6a	2003	3635
6b	2003	2720
6c	2003	1756
6d	2003	2447
7a	2005	7648
7b	2005	7469
7c	2005	7445
7d	2005	7648
8a	2005	7696
8b	2005	7696
8c	2005	7696
8d	2005	7696
9a	2004	7696
9b	2004	7696
9c	2004	7696
9d	2004	7696

Table 1. Description of classrooms, including room volume and year built.

Figure 1. Diagram of data collection set-up.



the single noise criteria (NC) of each classroom. Reverberation time (RT60) was measured at each of the five measurement locations using a Gold Line 60 Reverberation Time Meter. Measurements at each location were taken at .5, 1 and 2 KHz and averaged together. The five location measurements were then averaged to give a single RT60 measurement for each room. A noise burst generated by a Gold Line PN3 Pink Noise generator connected to an amplified speaker system served as the RT60 measurement stimulus. The speaker system was positioned in the front of the room at a height of about 5.5 feet approximating the height of a teacher standing in front of the classroom. See Figure 1 for the measurement arrangement.

Results

The background noise levels (dBA) in the thirty-six schools are shown in Figure 2. The average noise levels in the "old" schools ranged from 32.6 to 54.4 dBA. Only the four classrooms used for DHH children met the ANSI performance criterion of 35 dBA. The average noise levels in the "new" classrooms ranged from 31.0 to 52.9 dBA. Again, only classrooms used for DHH children met the ANSI criterion; one of the four classrooms did not meet the criterion. If measurements from classrooms for DHH children are removed from the averages, the background noise level for the "old" classrooms averaged 51.2 dBA and the levels for the "new" schools averaged 44.7 dBA. A two-tailed non-parametric Mann-Whitney test revealed a significant difference ($p < .002$) between the noise levels in the "old" and "new" classrooms. Although the "new" classrooms had a lower noise level, neither "old" nor "new classrooms met the ANSI noise criterion.

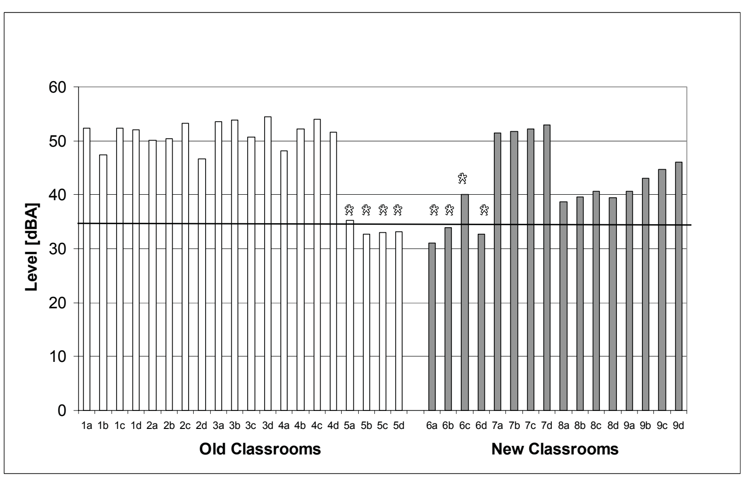


Figure 2: Average background noise levels in old and new schools. Numbers (1-9) represent the schools and letters (a-d) represent the classrooms. ☆ = classrooms for DHH children

While not an ANSI-2002 criterion, noise criteria

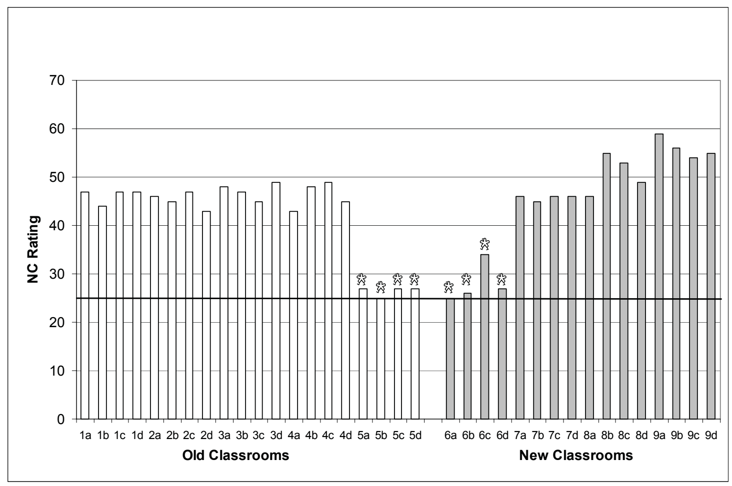


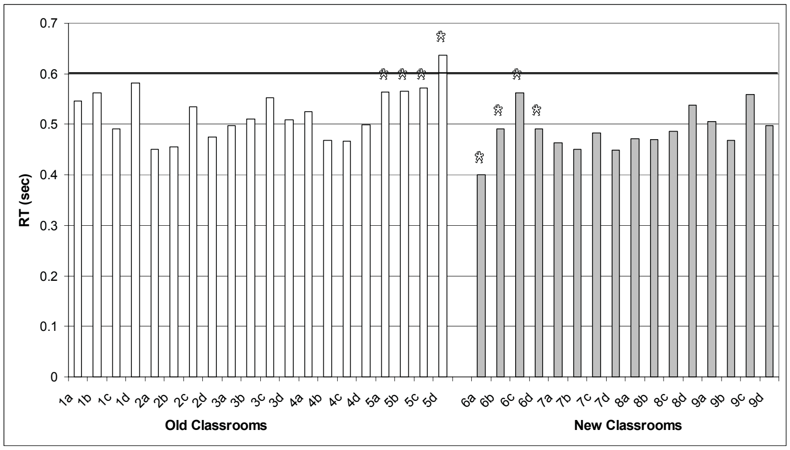
Figure 3: NC curve values for old and new schools. Numbers (1-9) represent the schools and letters (a-d) represent the classrooms. ☆ = classrooms for DHH children

curve measurements showed results similar to the single number noise measurements and are shown in Figure 3. Of the thirty-six classrooms, only two classrooms (both used for DHH children) met an acceptable classroom criterion of NC 25.

Reverberation time measurements (averages of RT60 at .5, 1 and 2 KHz at 5 locations) in the thirty-six classrooms were 0.45-0.64 seconds in the "old" schools and 0.40-0.56 seconds in the "new "schools. The reverberation times are shown in Figure 4 (see page 20)

It should be noted that classrooms in school #5 had twelve foot ceilings, the highest of all classrooms measured. The average RT60 of these classrooms was the highest (0.58 seconds) when compared to the other classrooms with lower ceilings. Because all of the classrooms except for one with an RT60 of 0.64 seconds (#5d) complied with the ANSI criterion of 0.6 seconds

Figure 4: Average reverberation times (RT) at 0.5, 1 and 2 kHz in old and new schools. Numbers (1-9) represent the schools and letters (a-d) represent the classrooms.
✩ = classrooms for DHH children



and because the measurement ranges were similar in the "old" and "new" classrooms, no further analyses were made of these data.

Discussion

This study was conducted to determine if old and new schools meet the ANSI standard for background noise level and reverberation time. Measurements were collected in thirty-six unoccupied classrooms. Results showed that all classrooms met the recommended reverberation times, however, most of the classrooms did not meet the recommended background noise levels. All 7 classrooms that met the acceptable noise criterion as specified in the ANSI standard were classrooms for DHH students. Four classrooms within a new school specifically designated for DHH children were included in the study as well as four classrooms from an old school with classrooms for DHH children. All four classrooms from the old school (built in 1916) met the ANSI standard for background noise levels of 35 dBA or less while three of the four classrooms from the new school (built in 2003) met the ANSI standard. The reason why one classroom did not meet the ANSI standard in the new school was perhaps due to airplane noise during the time of data collection. The school is located near a busy international airport and while obtaining measurements in that particular classroom, several large planes passed over the building. The children who are most challenged by adverse listening environments are those with hearing impairments, and it is comforting to find that these classrooms met acoustical standards for both reverberation and background noise levels. It should be noted, however, that DHH children and children with special needs in general are often mainstreamed in a school building and may have classes in rooms not specifically designated for them.

The difference between noise levels in the old and new classrooms is significant. Results from this study indicated that the background noise levels in the newer classrooms were slightly lower than the older classrooms. This statistically significant difference may be attributed to the variation in cooling systems between the two groups of classrooms. The old classrooms all had window or wall unit HVAC systems, whereas the new schools contained central cooling systems and/or ceiling fans. The centrally ducted HVAC systems were more common in the newly constructed schools, which may be indicative of a trend toward quieter classrooms. Despite the statistically significant difference between the old and new classrooms for children with normal hearing, new classrooms still did not meet the recommended ANSI standard for classroom noise levels. This suggests that even centrally ducted HVAC systems may not provide a complete solution to the noise problem. Central systems produce noise levels less than window and wall units, but still exceed the recommended 35 dBA level.

The most significant source of classroom noise is in the lower frequencies, which is commonly attributed to HVAC systems. The NC curve data confirm that the major source of noise generated in the classrooms is from the HVAC systems. If the HVAC systems had been turned off while measurements were collected, it is likely that the background noise levels would have been notably reduced. However, the measurements that are most representative of everyday classroom noise levels are with the HVAC systems turned on, as these systems run nearly continuously when schools are in session. There was some variation among the types of HVAC systems used in the old and new schools. All of the classrooms in the old schools, except the four classrooms for DHH children, had window units. Eight classrooms in the new schools had centrally-ducted HVAC systems and for these rooms background noise levels were still greater than the ANSI standards, but by a lesser degree (approximately 5-10 dB louder than the standard). Classroom #7b in a new school that emphasizes energy conservation had multiple ceiling fans in place of a HVAC system, yet background noise levels were still louder than the ANSI standard of 35 dBA with the fans turned to their lowest setting. These findings suggest that achieving quiet HVAC systems will be the largest challenge facing schools.

Reverberation times in all 36 classrooms met the ANSI recommendations of 0.6 seconds. This may be partly due to the fact that room modifications (i.e., carpeting, acoustic tiling, and corkboard) are more cost-effective and easier to achieve, as opposed to renovating a school's HVAC systems. All of the new schools and nearly all the old schools were carpeted and had acoustic ceiling tiles. In addition, cork-board and other absorptive materials were covering almost all wall space. This may account for the consistency among reverberation measurements across the 36 classrooms. It was not clear whether these room modifications were done specifically to improve the room acoustics, although they had that result.

Future considerations for studies in classroom acoustics may look to evaluate whether or not school administrations take into account the acoustical environment during the design and construction of new schools and what measures are performed in order to ensure acceptable acoustics. A cost-benefit analysis of acoustic modifications, including carpeting and centrally ducted HVAC, would be beneficial for old schools as well as for new schools that are being designed and constructed.

The results of this study suggest that undesirable background noise levels are a major problem in schools. The quality of the learning environment affects student achievement and one way this can be improved is by reducing background noise levels to acceptable limits. Despite the development of the ANSI S12.60-2002 standard, new schools appear to continue being built with classrooms that have background noise levels 10-15 dBA louder than recommended. It is obvious that in order to improve the listening, learning and teaching environment in the classroom setting, a consensus regarding and enforcement of specifications for classroom acoustics are needed. It is critical that parents, teachers and professionals advocate for quieter classrooms and, ideally, the implementation of a law requiring schools to consider background noise levels.

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