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AUTHOR	Smith, Melissa
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ABSTRACT

Asserting that without an adequate acoustical environment, learning activities can be hindered, this paper reviews the literature on classroom acoustics, particularly noise, reverberation, signal-to-noise ratio, task performance, and recommendations for improvement. Through this review, the paper seeks to determine whether portable classrooms provide acoustically adequate environments for learning. (Contains 63 references.) (EV)

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The Acoustical Environment

Melissa Smith
Doctoral Student
School Design and Planning Laboratory
University of Georgia

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The Acoustical Environment

"The acoustical environment is defined as that mixture of background noise and useful sounds in which we continually find ourselves"(Borrild, 1978, p.147). The acoustical characteristics of an environment can be crucial depending on the activities of that environment (Jones & Broadbent, 1991). The classroom environment is one environment in which the acoustics would be greatly influential. A classroom is a place where a group of 20 or more children and one adult gather and engage in learning activities requiring listening. Siebert (1999) reported that teachers spend 6.3 hours each day talking, while Berg (1987) reported that 45% of the day student activities at school require listening. Without an adequate acoustical environment, learning activities can be hindered. Noise, reverberation, signal-to-noise ratio, task performance and recommendations for improvement will be reviewed as the literature on room acoustics is presented. Through this review and a teacher questionnaire, the researcher hopes to determine whether portable classrooms provide acoustically adequate environments for learning.

Noise

Elementary school classrooms can be noisy places. As teachers instruct and children move about involved in activities or otherwise, the acoustical environment in a classroom can be quite noisy. This noise typically is a result of ventilation systems, poor insulation, hard surfaces that reflect noise, and outside noise (Anderson, 2001). According to the American Speech, Language, and Hearing Association (1995), sources of noise inside classrooms include students talking, desks and chairs sliding on the floor, and books and papers shuffling. It is this noise that is most detrimental to learning because of the similar frequency of the teacher's voice, known as the signal (ASHA, 1995). Students

are exposed to noise in addition to noise found inside classrooms. Classrooms are exposed to external noise such as airplanes and cars, and internal noise such as hall traffic and playgrounds in addition to the noise produced inside the classroom (Crandell & Smaldino, 2000). The combination of these three types of noise produces classrooms that exceed recommended noise levels.

"It is not only the pressure level of sound, expressed in decibels, which is important in evaluating the sound situation at a school, but also the kinds of sounds" (Hammon, 1970, p.14). There are generally three types of classroom noises identified: Background noise, internal noise, and external noise (ASHA, 1995; Borrild, 1978; Crandell & Smaldino, 2000; Crum & Matkin, 1976). In addition to these, Glass (1985) refers to useful noise such as the teacher speaking as the signal. Noise, other than the signal or desired noise, which interferes with the child's need to hear and understand, is known as background noise (Crandell & Smaldino, 2000).

Background noise is steady in nature and can consist of heating and air conditioning systems, automobile traffic, or a cafeteria full of students (Berg, 1993). In a study by Sanders, he analyzed 15 schools and 47 classrooms in an attempt to generalize about noise levels in classrooms. Sanders (1965) reports background noise of the average classroom is equal to the level of the teacher's voice. As the teacher raises her voice, attempting to overcome background noise, overall stress levels of students and the teacher are increased (Anderson, 2001).

In addition to background noise, Berg (1993) refers to sudden, temporary noises such as footsteps, a jet passing by, or playground yells as intruding noise. These noises are spontaneous and unpredictable. Finally, internal noises are those noises generated within

the classroom such as talking, chair and table movement, and student movement (Berg, 1993). Noise of this nature has been shown to contribute to a constant state of aggravation (Glass, 1985) and restlessness, increased activity levels, and increased self-generated noise (Anderson, 2001). These types of behaviors do not lend themselves to learning.

Several studies have been conducted measuring sound levels in classrooms at various times. As previously mentioned, Sanders (1965) reported on 47 classrooms in 15 schools. He concluded that noise levels remained below 65dB for 60% of the school day. Kindergarten classes were found to have slightly higher noise levels as a result of the type of activities of a kindergarten classroom (Sanders, 1965). In a more recent study by Berg (1993), unoccupied classrooms, at night, measured at 30-35dB, while with the HVAC system on, levels raised to 40-50dB. This level is raised to 55-75dB with a teacher and 25 students in the classroom (Berg, 1993). Levels of noise in classrooms are reported at 15-20dB higher than the recommended levels of 40-50dB (Crandell & Smaldino, 1994; Berg, 1993). A useful noise, such as the teacher speaking, is measured at approximately 35dB-60dB which can be easily masked by the other sources of noise (Glass, 1985). As will be discussed, these levels are detrimental to student learning.

Signal-to-Noise Ratio and Reverberation

The acoustical environment of a classroom is measured in two ways: Signal-to-noise ratio and reverberation time. By examining these two measurements, the environment can be evaluated. Signal-to-noise ratios and reverberation times have repeated shown an impact on the intelligibility of speech, which is vital in a classroom setting.

A signal-to-noise ratio is a difference between the intensity of a signal and the intensity of the background noise (Berg, 1993; Crandell & Smaldino, 2000; Erdreich, 1999). This ratio can be found by subtracting the background noise, in decibels, from the signal reading in decibels. A ratio of 9dB or greater will yield an environment for acceptable speech intelligibility, while 3dB or less create an unacceptable listening environment (Erdreich, 1999). "Speech intelligibility is the ability of a student to hear and correctly interpret instruction or discussion" (Johnson, 2001, p.28). The signal or speech of the speaker and the source of noise are the two crucial factors of a signal-to-noise ratio. To improve this ratio, the signal must be increased or the noise decreased (Erdreich, 1999).

Reverberation is another indicator of the speech intelligibility of a classroom. Reverberation refers to time, in seconds, it takes for a sound from a source to decrease 60dB once the source of sound stops, or more technically, "...the persistence or prolongation of sound within an enclosure as sound waves reflect off hard surfaces" (Crandell & Smaldino, 2000, p.365). Reverberation has also been referred to as reflected sound that is delayed in reaching the receiver (Finitzo-Hieber & Tillman, 1978). Reverberation, or repeated reflection of sound, is found by multiplying volume(length x width x height) by 0.05 and dividing that product by the total absorption (Berg, 1993). The surface absorption of objects in the room has the most influence on the reverberation time of sounds in that room (Berg, 1993). Typical reverberation times within a classroom are 0.35 to 1.20 (Crandell & Smaldino, 1994), while the recommended reverberation time is 0.4 seconds or less (Finitzo-Hieber & Tillman, 1978; Crandell & Smaldino, 2000).

Student learning is affected by high reverberation times and low signal-to-ratio signals because of the lack of speech intelligibility (Borrild, 1978; Crandell & Smaldino, 2000; Finitzo-Hieber & Tillman, 1978). Reverberation can cause a build up of sound, which results in a lower signal-to-noise ratio (Erdreich, 1999). This build up affects speech intelligibility by masking sounds within words. "Vowel sounds are 10dB-15dB louder than consonant sounds" (Berg, 1993, p.32). Long reverberation times cause speech to blur as these vowel sounds in words mask consonant sounds (Erdreich, 1999; Berg, 1993; Crandell, Smaldino, & Flexer, 1995). Syllables of words are 1/5 of a second, while rests between words are 1/3 of a second (Glass, 1985). These too can be masked by reverberation (Crandell, Smaldino, & Flexer, 1995). In a learning environment, where listening is crucial, a situation in which parts of speech are masked is detrimental.

The impact of various reverberation times has given researchers valuable information about ideal environments. In a study conducted by Crandell and Smaldino (2000), children placed in an environment with a signal-to-noise ration of +6dB and a reverberation time of 0.4 seconds recognized 71% of the stimuli. As the signal-to-noise ratio decreases and the reverberation time increases, student intelligibility decreases. In an environment with a signal-to-noise ratio of 0dB with a reverberation time of 1.2 seconds, students recognized less than 30% of the stimuli (Crandell & Smaldino, 2000). Finitzo-Hieber and Tilman (1978) examined the affects of reverberation times on normal and hearing-impaired children. Groups of 12 hearing impaired and 12 normal hearing children, ranging in age from 8 years, 8 months to 13 years, 9 months, were exposed to reverberation times of 0.0, 0.4, and 1.2 seconds. Acoustically treated surfaces were used to alter reverberation times. As reverberation times increased, word discrimination

decreased in both groups. The normal hearing group of children experienced an 18% decrease in word discrimination. Erdreich(1999) reported that minimally adequate classroom environments with competing noise become inadequate with as little as 1 second reverberation time. In another study, only 9 out of 32 classrooms, or 27%, had a reverberation time of 0.4 or less (Crandell and Smaldino, 1995). While research shows the ill effects of high reverberation times, this seems to be the norm for classrooms

Reverberation and signal-to-noise ratios are two components of the acoustical environment. These two, in combination, have profound effects on the ability of those in the environment to perceive speech. Ideal learning environments are those with a signal-to-noise ratio of 9dB or greater and reverberation time of 0.4 seconds. As study after study have shown, this is not the status of our current classroom environments.

Human Performance

Classrooms are places where students and teachers are expected to perform a variety of tasks. Berg (1987) reported that 45% of a child's day at school involves listening. "Listening is a required communication skill for students in all subjects taught in school" (Berg, 1993). Not only is listening or speech intelligibility impaired, but task performance in the presence of noise can be affected as well. In combination, a majority of the activities conducted in a classroom are influenced by noise.

Many factors contribute to students' difficulties with speech intelligibility in the classroom. While ages vary slightly, 13 to 15 years of age, many researchers have found that young children have not fully developed the ability to decipher between speech and noise; A skill known as figure-ground discrimination (Crandell & Smaldino, 2000; Nelson & Soli, 2000; Crandell, et al., 1995; Anderson, 2001). In addition, Anderson

(2001) identifies children as individuals with short attention spans and high distractibility. Not only are these developmental issues present, Flexer (1989) found that 30-43% of elementary students have minimal hearing impairment that is either permanent or fluctuating. Children of this age are susceptible to colds, ear infections, and allergies (Anderson, 1997). Finally, Palmer (1997, p. 215) notes, "Adults can fill in missing information using prior experiences. Children are limited and therefore are not able to fill in as many missing pieces of a message". With these limitations, elementary school children are at a disadvantage even in the best acoustical environment.

In a study conducted by Hougast (1981), the effect of noise conditions on speech intelligibility examined 20 teachers and 500 students under three noise conditions. This study attempted to determine if a relationship exists between noise level and speech intelligibility. As a point of reference, the first environment was free of reverberation and interfering noise. The second condition involved reverberation, but was without interference. The third condition placed students and teachers in an environment with both reverberation and interference of road traffic. The results of this study found that for approximately 20% of teachers, speech intelligibility of students is affected when the outside noise reaches 50dB.

Teachers experience difficulties as a result of poor acoustical environments of a different nature than those of students. Erdreich (1999) describes the Lombard effect as the situation in which the teacher raises her voice to overcome the noise in the classroom only to have the classroom noise get louder requiring her to raise her voice even more. Situations like these lead to voice disorders in teachers (Crandell, et al., 1995; Rittner-Heir, 2000). In a study conducted by Ko (1979), the affects of background noise on

teacher performance were examined. Ko found that teachers faced with significant background noise were fatigued, tense and experienced discomfort compared to those teachers not exposed to background noise. Teachers in Ko's study also reported that this background noise interfered with their teaching. Barriers such as these make a difficult job even more difficult.

As teachers attempt to teach and students attempt to perceive this instruction, noise can be a difficult barrier to overcome. "Background noise affects students' abilities to perceive speech by making acoustic and linguistic cue in the teacher's spoken message (Crandell & Smaldino, 2000, p. 364). Without being able to fully understand the teacher's instruction, learning abilities are hindered (Nelson & Soli, 2000). Certain students are at higher risk in these environments. Students learning English as a second language, attention deficit disorder students, and those with undetected hearing loss fall even further behind when faced with issues of noise (Nelson & Soli, 2000; Rittner-Heir, 2000; Berg, 1993; Johnson, 2001). Thus the problems of these students are compounded.

Instructional practices in poor acoustical environment may require changes. Anderson(2001) notes that in noisy classrooms instructions must be repeated, group discussion is ineffective as students cannot hear each other's voices, and students learning to read have difficulty hearing the differences between words. In addition, the type of instruction used by teachers is worthy of consideration. Lecture-style instruction results in a 6-9dB drop in the level of the teacher's voice from the teacher to the back of the room (Siebein, Gold, Siebien, Ermann, 2000). Alternative methods such as small groups or special desk arrangements can improve this rate (Siebein, et al., 2000). Poor

acoustical classrooms cause students to have difficultly staying on task and decreased engagement (Berg, 1993).

Students receive two types of stimuli from the teacher in a classroom: Direct sound and reflected sound (Berg, 1993). The child's location in the classroom determines the combination of the two sounds that the child receives and the acoustical quality of the classroom would determine the amount of reflected sound. Speech in classroom must be understood, not just merely heard (Glass, 1985). HVAC systems and other sources of background noise yield learning deficits, teacher fatigue, and off-task behaviors by students (Nelson & Soli, 2000). "The effect of noise is dependent on the type of noise and demands made by the task such as familiarity with the work and use of words required for the work" (Jones & Broadbent, 1991).

"Steady noise does not interfere with human performance unless it inconsistently exceeds 90dB" (Glass, 1985, p.10). Even at 100dB, these continuous sounds, which tend to become familiar, do not affect simple task performance (Jones and Broadbent, 1991). While simple tasks are not affected by noise, complex tasks are more affected (Boggs & Simon, 1968; Jones & Broadbent, 1991). Jones and Broadbent defined a complex task disrupted by noise as one that is "cognitively burdensome, unpredictiable, or requiring an accumulation of evidence"(p. 24.4). Fluctuations in noise yield inefficiencies proportional to the to change in sound (Jones and Broadbent, 1991). Even more than fluctuations, Jones and Broadbent found that sudden bursts of noise interrupt task performance for 2 to 3 seconds and up to 30 seconds, and these burst drastically affect tasks involving hand-eye coordination. Jones and Broadbent found that inefficiencies resulting from noise are short-lived not extended. For example, noise was found to slow

the rate of addition, but this impairment disappears after several problems (Jones and Broadbent). In addition to these factors, the child's attitude toward the noise determines the influence the noise has on performance (Jones and Broadbent). If the child feels in control and expects the noise, the interruption is much less (Jones and Broadbent). Speech, understood and irrelevant to the task at hand, even as low as 55dB, results in performance impairment (Jones and Broadbent, 1991). While working in noisy conditions, if faced with multiple tasks, the child will limit efforts to the dominant task and dominant method of achieving this task (Jones and Broadbent). Jones and Broadbent used the example of memorizing a list in a noisy environment which would cause some students to use a method of repeated the list repeatedly aloud. As presented, there are a variety of ways noise can be influential and detrimental to learning environment.

As has been discussed, the acoustical environment can have a profound effect on a child's ability to perform in the classroom. Not only is the student affected, the teacher experiences difficulties as well. With this information known, the planners, architects, and construction managers have a responsibility to correct these problems. The quality of public education can be drastically improved by eliminating factors prohibiting children from hearing in the classroom.

Solutions

Currently, the U.S. Architectural and Transportation Barriers Compliance Board or Access Board has drafted guidelines to improve acoustics in classrooms (Anderson, Smaldino, Crandell, 2000). As a standard of the Americans with Disabilities Act, the goal of this movement is to establish national standards for acoustics in classrooms.

While this is still under consideration and has not been finalized, it is a step in the direction of improving the acoustical environment of classrooms.

"Good acoustics in a building result from adequate planning and building designs" (Glass, 1985, p.8). Crum and Matkin (1976) identify four major areas of concern when treating an environment acoustically: ceiling, floors, walls, large areas of glass. Reflective surfaces must be designed to absorb more sound. Installing acoustical tile in the ceiling and carpet on the floor covers 60% of the surface area drastically decreasing reverberation, thus improving the listening environment. (Crum & Matkin, 1976). Treating the walls can be achieved by installing book shelves, dividers, acoustic wall panels, and draperies to absorb sound and decrease reflections of sound (Crum & Matkin, 1976). Decreasing background noise can be achieved by lining ductwork with acoustic liners (Johnson, 2001). Crum and Matkin identify the most difficult problem to correct is noise from adjacent areas. Castaldi (1994) recommends selecting a site with limited access to noise and arranging the layout of the school such that noisy places are isolated. Sound field amplification is another alternative to improve students' listening abilities (Anderson, 2001; Berg, 1993). According to Berg (1993), sound field amplification is the most cost-effective method of improving the listening environment. Anderson (2001) questions the budget allotment for acoustics of less than 1%. This percentage is less than the amount spent on landscaping. As this problem is recognized, changes in monetary allotments will be required to make classrooms adequate acoustical environments. Regardless of the method chosen, decreasing noise and sound reflections has been proven to benefit students in the classroom environment.

Noise, reverberation, signal-to-noise ratio, and task performance within noisy conditions provide an overall view of the impact of the acoustical environment on children. As school systems decide on learning environments for children, portable classrooms for example, these factors must be considered. Student learning and achievement is the overall goal of public education. Therefore, providing an adequate listening environment will improve the achievement of students.

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