SchoolS

Classroom Acoustics: The Problem, Impact, and Solution

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In a classroom, speech is conveyed from the teacher to students through a combination of direct and reflected sound. Direct sound travels from its source in a straight line to the listener without being reflected. Reflected sound strikes one or more objects or surfaces in a room before reaching the listener (Everest, 1989; Hirschorn, 1989). Direct sound energy is most prevalent at distances close to the teacher, and reflected sound is the major source of energy at distances removed from the teacher (Davis & Jones, 1989). When combined appropriately in a quiet classroom, direct and reflected sounds enhance classroom communication and enable all students in the classroom to hear the teacher (Brook, 1991).

ABSTRACT: Classroom acoustics are generally overlooked in American education. Noise, echoes, reverberation, and room modes typically interfere with the ability of listeners to understand speech. The effect of all of these acoustical parameters on teaching and learning in school needs to be researched more fully. Research has shown that these acoustical problems are commonplace in new as well as older schools, and when carried to an extreme, can greatly affect a child's ability to understand what is said (Barton, 1989; Blair, 1990; Crandell, 1991; Finitzo, 1988). The precise reason for overlooking these principles needs to be studied more fully. Recently, however, acoustic principles have been clarified, and technologies for measuring room acoustics and providing sound systems have become available to solve many of the acoustical problem in classrooms (Berg, 1993; Brook, 1991; D'Antonio, 1989; Davis & Davis, 1991; Davis & Jones, 1989; Eargle, 1989; Egan, 1988; Everest, 1987, 1989; Foreman, 1991; Hedeen, 1980). This article describes parameters of the problem, its impact on students and teachers, and four possible solutions to the problem. These solutions are noise control, signal control without amplification, individual amplification systems, and sound field amplification systems.

KEY WORDS: classrooms, acoustics, listening

If being in a classroom was the same as being outdoors, most students would have a difficult time hearing and understanding the classroom teacher because direct sound alone is relatively weak (Davis & Davis, 1987; Everest, 1989). The power of the human voice, even at close proximity, is relatively weak, measurable only in microwatts (Fletcher, 1953). With normal vocal effort, the adult human voice is usually less than 60 dB SPL at a distance of 3 feet (Brook & Uzzle, 1987). Then, as the voice is propagated beyond 3 feet, its sound intensity decreases even more. The intensity decrease with distance is determined by a combination of factors, including the inverse square law (6 dB decrease with each doubling of distance), the directionality of sound, and the absorption of the sound by students who are directly between the teacher and distant students (Egan, 1988).

As stated previously, reflected sound can enhance direct sound, making it easier to hear speech. In order for reflected sound energy to be maximally beneficial in a classroom, the room should be designed to have an appropriate combination of reflective, absorptive, and diffusive surfaces. To primarily reflect sound, a surface must be flat or curved, as well as stiff and hard. Additionally, it must be several times greater in length or width than the wavelengths of the incident sounds. To primarily absorb sound, a surface can be of any shape, but it must be porous, diaphragmatic, or resonant. Surfaces that are irregular so that sound scatters in many directions will primarily diffuse sound (D'Antonio, 1989). Rooms designed primarily for listening to speech do not need a great deal of sound diffusion (Brook, 1991), but the reflective and absorptive characteristics of the room are critically important.

When not controlled properly, the reflection and absorption of sounds can interfere with classroom listening. For example, some of the most frequently used absorbent materials in school classrooms are acoustic ceiling tile and carpet on foam rubber padding. These materials absorb high-frequency sounds much better than low-frequency sounds. When the ceiling and floor are treated with these materials, consonant sounds, which are primarily high frequency, are not reflected well, and speech intelligibility is degraded (Everest, 1989; Harris, 1955). Although the treatment in the room has decreased some aspects of reverberation, it may actually interfere with speech intelligibility. The actual effects of ceiling treatment and carpeting on speech recognition have not been reported in the literature and more research in this area is needed.

There are several types of reflected sounds that occur within a room, including room modes, echoes, and reverberation. Room modes are room resonances that cause standing waves with "dead" and "live" spots and degrade speech within the frequency region of 80–300 Hz (Everest, 1991b). Echoes are reflected sound waves that are delayed and sufficiently intense to be distinct from the original sound source. They are likely to occur in classrooms where the back wall has a hard surface. Echoes are not usually heard as discrete phenomena, but they influence the level, quality, and intelligibility of the sound (Everest, 1989, 1991b). Echoes can have energy between 80–8000 Hz and have a major degrading effect on speech intelligibility. Even though much emphasis has been placed on reverberation in the past, classroom echoes are often more of a problem than classroom reverberation (Davis & Davis, 1987, 1991).

Reverberation, a term widely used by audiologists, is a prolongation or repeated reflection of sound. Reverberation time (RT), or the time it takes for a sound to decay 60 dB from its original intensity, varies dependent on the amount of absorption provided by the surfaces of the room. The primary effect of excessive reverberation, resulting from too much reflective surface in a room, is that the vowels of speech mask the lower intensity consonants and thus degrade speech intelligibility (Everest, 1989; Nabelek & Letowski, 1985; Nabelek & Nabelek, 1985; Nabelek & Robinson, 1982). It has been recommended that the reverberation time of a classroom be approximately 0.5 seconds for school children with normal hearing and approximately 0.3 seconds for school children with hearing impairments (Brook, 1991; Brook & Uzzle, 1987). The actual reverberation time of school classrooms in the United States varies from 0.3 seconds to greater than 1.5 seconds (Berg, 1987; Crandell, 1991; Finitzo, 1988). The reverberation times of a room should also be reasonably uniform across the speech frequency range (Everest, 1987). School classrooms often have much greater reverberation times at low frequencies than at high frequencies, contributing to the masking of consonants by vowels (Berg, 1993; Harris, 1955).

Although room modes, echoes, and reverberation can affect speech intelligibility in a classroom, the most serious acoustical problem in school classrooms is excessive noise, which masks the teacher's speech. In order for students to listen effectively, the noise level for an unoccupied classroom during school time should not exceed 35–40 dBA; for an occupied classroom, the noise should be no higher than 40–50 dBA (Crandell, 1991; Finitzo, 1988). Classroom noise levels have been found to be 30–35 dBA at night or over a weekend, 40–50 dB when the heating, ventilating, and air conditioning (HVAC) system is turned on, and 55–75 dB when a teacher and 25 or more students are in the room (Berg, 1993; Crandell, 1991; Finitzo, 1988). The typical noise level of school classrooms is 60 dBA, which is greater than the conversational voice level of many teachers, thus making it difficult for the students to hear the teacher. At certain times during the school day, the noise level of occupied school classrooms can reach 75–85 dBA (Barton, 1989; Finitzo, 1988; Ross, 1982), causing a very difficult, if not impossible, listening environment for the students.

THE IMPACT

Several studies have focused on the effects of noise, distance, and reverberation time on speech recognition. Additionally, there is now more attention being paid to the listening problems of special students, to student disengagement, to the teacher's voice, and to teacher fatigue (Allen, 1991; Berg, 1993; Cangelossi, 1988, 1991; Child & Johnson, 1991; Cooper, 1989; Crandell, 1991; Flexer, 1992; Fulmer, 1991; Johnson; 1991; Ray, 1990).

The effects of noise and reverberation on speech recognition scores of school children who have normal hearing and school children who are hard of hearing were studied by Finitzo-Hieber & Tillman (1978). When tested in an audiometric booth with negligible noise and reverberation, the students with normal hearing had mean speech recognition scores of 95%, and the students with hearing loss had mean speech recognition scores of 83%. In an experimental classroom, their recognition scores were compared at signal-to-noise (S/N) ratios of 0 dB, +6 dB, and +12 dB in combination with RTs of 0.4 and 1.2 seconds. The word recognition scores were obtained at a distance of 12 feet, simulating class instruction. The scores of the students with normal hearing varied from 30% to 83%, whereas the scores of the students who were hard of hearing varied from 15% to 60%. Both noise and reverberation degraded speech recognition, and the combination of the two was especially detrimental.

A recent study of the impact of teacher–student distance on speech recognition scores was conducted with children from 5 to 7 years of age by Crandell (1990). Lists of syntactically simple sentences were presented in a 59 dB SPL noise field in an experimental classroom. The S/N ratio decreased from +6 dB at 12 feet to -3 dB at 24 feet. The overall RT for the room was 0.46 seconds. All subjects scored 90% or better in quiet at 65 dB SPL. Mean scores for the children, all of whom had normal hearing, were 82%, 55%, and 36% at 6, 12, and 24 feet, respectively.

Leavitt and Flexer (1991) used Rapid Speech Transmission Index (RASTI) measurements to identify the integrity of speech at various locations in a college classroom. The transmitter, which was located in the front of the classroom, produced a signal to simulate a teacher talking at 59 dBA at a distance of 1 meter. The overall RT of the room was 0.65 seconds. A RASTI score of 1.0, which indicated perfect replication of the signal, was obtained only at a

6-inch reference position. The scores measured in the classroom were in the .80 range for six front row seats and fell to the .60 range for the back row seats. This indicated that the speech signal in the back of the room was degraded when compared to that in the front of the room.

Acoustical problems in schools seem to exacerbate the learning difficulties of school beginners, second-language learners, children with learning deficits, and youngsters with hearing losses (Berg, 1993; Crandell, 1990). School beginners have problems learning in classrooms because their speech, language, and listening skills have not matured, making it difficult for both teachers and young students to communicate with each other (Durkin, 1986; Edwards & Mercer, 1986; Nippold, 1988; Romaine, 1984). When a student uses English as a second language, poor classroom acoustics may further compromise the child's ability to learn (Williams & Capizzi-Snipper, 1990). Children with learning deficits may also be negatively affected by poor classroom acoustics because they frequently have phonologic, semantic, syntactic, and pragmatic language disorders that limit their communication competencies (Bos, 1988; Lansky & Chapandy, 1976; Lupert, 1981; Lyon & Risucci, 1988; Scruggs, 1988; Simon, 1985; Wiig & Semel, 1976).

As discussed earlier, Finitzo-Hieber and Tillman (1978) showed that students with bilateral hearing losses are negatively affected by poor classroom acoustics. This finding has been verified by other researchers and has been shown to be true for children with minimal hearing losses and unilateral losses also (Bess, 1982; Finitzo-Hieber & Tillman, 1978: Quigley & Thomure, 1968; Ross, 1982).

When students cannot listen effectively in school, they are more likely to have difficulty staying on task, and discipline and cooperation are difficult to maintain (Gallup, 1986). In noisy classrooms, many teachers make vocal adjustments in order to maintain classroom control and to reach desirable S/N ratios (Ray, 1990). Some teachers have inherently strong voices and are able to project their voices for long periods of time without tiring. Other teachers, however, have relatively weak voices and become stressed when forced to raise their voice level. When teachers use their voices to compensate for high noise levels, they are also more tired at the end of the school day (Berg, 1993). Sometimes, classroom noise levels are too high for any teacher to overcome with vocal effort, and abuse and damage to a teacher's vocal mechanism may result (Child & Johnson, 1991).

THE SOLUTION

In order to improve the listening, learning, and teaching environment in a classroom, several different approaches have been used. Attempts have been made to reduce the levels of noise in school, to improve the signal without amplification, to use individual amplification systems, and to use sound field amplification systems. In any specific situation, it is likely that a combination of several of these strategies will be most useful (Berg, 1993).

Noise Control

It is absolutely essential that schools be designed or modified to reduce occupied classroom noise levels to less than 50 dBA so that speech communication is not masked (Berg, 1993; Ross, 1982). The many airborne and structure-borne noises outside the school, inside the school, and within classrooms need to be identified, measured, and either isolated or reduced (Berg, 1993; Crandell, 1991; Finitzo, 1988). This can be facilitated with a noise control plan that describes current noise levels, provides general and specific objectives, determines the person responsible for implementing this plan, and describes evaluation procedures (Berg, 1987, 1993). When feasible, architects, engineers, educational audiologists, and other school personnel should collaborate to provide for reduced noise levels in the school (Berg, 1993).

Signal Control Without Amplification

With reduced noise in the classroom, a S/N ratio of +10 dB is possible. This S/N ratio will not degrade speech intelligibility for most students if classroom resonances, echoes, and reverberation are controlled (Berg, 1993; Brook, 1991; Davis & Davis, 1991; Everest, 1991a, 1991b, 1991c). In order to improve the acoustical environment of a classroom, one or more of the following suggestion can be implemented:

- Make all surface areas that do not provide useful reflection absorbent, and, conversely, do not cover any useful reflective surfaces (Brook & Uzzle, 1987).
- Make the ceiling and side walls reflective surfaces in order to increase the signal intensity.
- Install carpet on the floor to cover a useless reflecting surface and reduce noise (however, as suggested earlier, the combination of ceiling treatments and floor treatments needs to researched more fully).
- Place absorbent panels on the back wall in order to prevent echoes and reduce reverberation.

Use of Individual Amplification Systems

Individual amplification systems are often used by children with hearing losses and by selected youngsters with learning difficulties in order to improve their ability to listen in the classroom (Berg, 1993; Davis, 1991; Maxon & Smaldino, 1991; Viehweg, 1986). These systems include personal hearing aids, nonprescriptive amplifiers, personal FM systems, loop FM systems, and infrared systems. Each type of system has distinctive components, features, roles, and comparative advantages and limitations (Finitzo, 1988; Radcliffe, 1991; Sandlin, 1991). To ensure effectiveness for each student, a particular system must be carefully selected, evaluated, and maintained (Garstecki, Wilber, Stein, & Pasa, 1991; Mueller, Hawkins & Northern, 1992; Ross, 1992). If these steps are taken, hearing aids will enable students with hearing losses to hear teachers at close distances under quiet conditions, and personal FM systems, loop systems, and infrared systems will assist students with hearing losses and learning difficulties in hearing teachers across classrooms under poor acoustical conditions.

Use of Sound Field Amplification Systems

Perhaps the most cost-effective and acceptable technology for facilitating learning in a typical school classroom is the use of a sound field FM system (Ray, 1990; Sarff, Ray, & Bagwell, 1981). This type of FM system has loudspeakers that allow groups or an entire class of students to listen to the teacher's voice at an improved S/N ratio, no matter where the teacher is in the classroom (Berg, 1987; Flexer, 1992). Compared to other amplification systems used in classrooms, sound field FM systems reach more students and are subject to the least amount of downtime as a result of malfunction (Anderson, 1989). When Blair, Myrup, and Viehweg (1989) compared the speech recognition scores obtained by children with hearing losses (average losses of 50 dB HL) using several different amplification systems, they found that the scores obtained with a sound field FM system were nearly as high as those obtained with personal FM amplification. The speech recognition scores with the sound field FM system were higher than when just personal hearing aids were used.

SUMMARY

Classroom acoustics is a widespread educational problem that requires additional research. Poor acoustical environments in schools are causing the degradation of the speech signal, which may increase off-task student behavior, and may contribute to teachers' voice problems and fatigue. All teachers and students, particularly those with special communication problems, are potentially negatively affected by poor classroom acoustics. Poor acoustics in the classroom can be improved through noise and signal control measures and through the use of individual, group, and classroom amplification systems. It is incumbent on those working in or with school systems to be aware of the problems caused by poor classroom acoustics, the impact poor acoustics may have on both the teacher and the student, and ways to improve the acoustic environment of the classroom.

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