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ABSTRACT

This booklet explores classroom acoustics and their importance on the learning potential of children with hearing loss and related disabilities. The booklet also reviews research on classroom acoustics and the need for the development of classroom acoustics standards. Chapters examine: 1) a speech-perception model demonstrating the linkage between classroom acoustics adequacy and the development of a speech and language system, 2) the benefits of improving classroom acoustics by removing current acoustic barriers, 3) procedures for evaluating, measuring, and modifying noise and reverberation levels in the classroom environment, and 4) acoustic, technological, and rehabilitative solutions for improving classroom acoustics and speech perception in the classroom setting. References follow each chapter. (GR)

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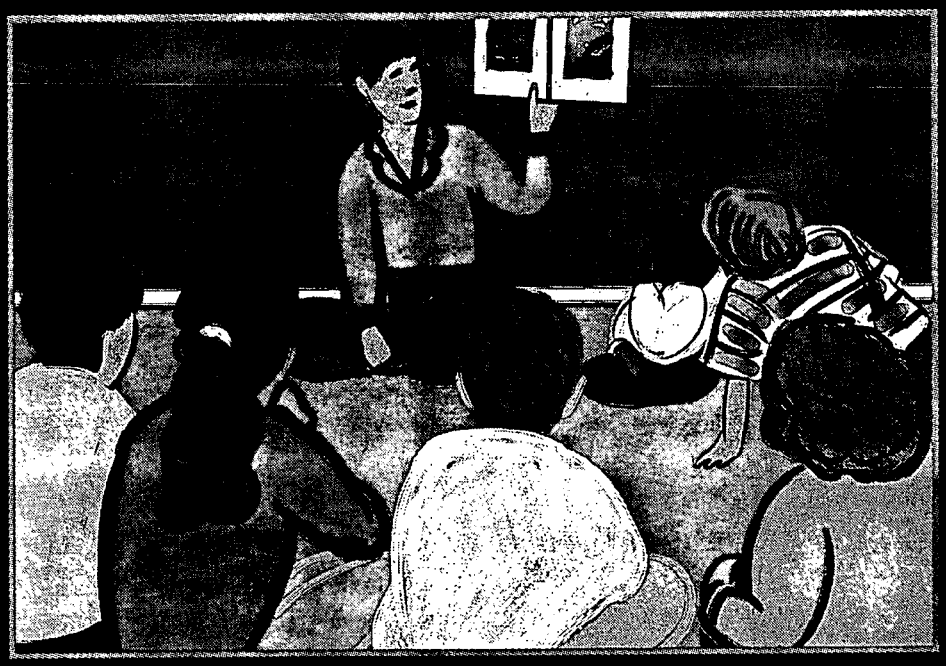
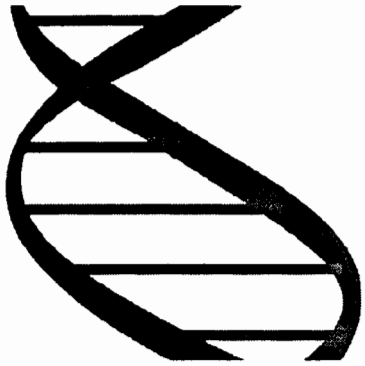
Alexander Graham Bell Association for the Deaf and Hard of Hearing



Classroom Acoustics: Understanding Barriers to Learning

Edited by

Carl C. Crandell, Ph.D., and
Joseph J. Smaldino, Ph.D.

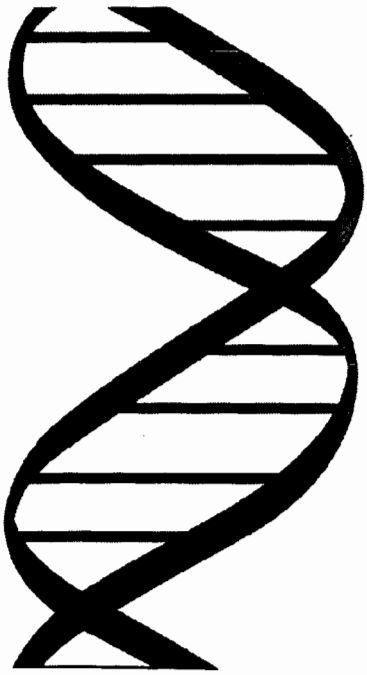


AGBell

The Alexander Graham Bell Association for the Deaf and Hard of Hearing
2001 Summer Conference

The Human Genome Project and Hearing Loss

Friday, July 27, 2001–
Sunday, July 29, 2001
Hyatt Regency Bethesda
One Bethesda Metro Center–
Wisconsin Avenue at
Old Georgetown Road
Bethesda, MD



"This Is An Adventure Into Ourselves..." Join AG Bell, Francis Collins, M.D., Ph.D., and seven other distinguished scientists and physicians for a lively and interactive program that will provide a comprehensive overview of the latest research on genetics, hearing loss, and possible gene-based treatments for deafness. The conference is intended for those with an interest in hearing loss, but not necessarily with a scientific background. All attendees will receive a copy of the Conference Proceedings.

Preliminary Conference Schedule

Friday, July 27
7:00 pm - 9:00 pm
The Human Genome Project: Healthcare Implications - Francis Collins, M.D., Ph.D., Director of the Human Genome Institute

Welcome Reception immediately following.

Saturday, July 28
8:15 a.m. - 12:15 p.m.

- "The Role of NIH in Gene Identification Initiatives" - James F. Battey, Jr., M.D., Ph.D., National Institute on Deafness and Other Communication Disorders (NIDCD), National Institutes of Health
- "Introduction to Genes and Hearing Loss" -Bronya Keats, Ph.D., Louisiana State University Health Sciences Center
- "Audiological Testing and Identification of Hearing Loss Genes" - Charles Berlin, Ph.D., Louisiana State University Health Sciences Center
- "Nonsyndromic Hearing Loss: Identifying Genes and Mechanisms" - Arti Pandya, M.D., M.B.A., Virginia Commonwealth University
- "Syndromic Hearing Loss: Identifying Genes and Mechanisms" - Andrew Griffith, M.D., Ph.D., NIDCD Laboratory of Molecular Genetics and Neuro-otology Branch
- "Genetic Testing: Benefits and Limitations" - Heidi Rehm, Ph.D., Harvard Medical School
- "Hair Cell Regeneration: The Potential for Gene-Based Approaches" - Margaret Lomax, Ph.D., University of Michigan

Educational Sessions, running concurrently on Saturday, July 28 and Sunday, July 29

- "How to Get the Best Diagnostic and Management Services for your Child with Hearing Loss" - Charles Berlin, Ph.D. Bring your child's audiogram to this session!
- "Listening and Literacy" - Carol Flexer, Ph.D., and Lyn Robertson, Ph.D.
- "Raising a Child with Hearing Loss: Parent Perspectives" - Moderator: Virginia Stern
- "How to Make a Case for Classroom Acoustics" - Donna L. Sorkin
- "Educational Legislation for Parents and Professional" - John Flanders, J.D.
- "An Introduction to the Auditory-Verbal Approach for Children with Hearing Loss" - Ellen A. Rhoades, Ed.S.
- "Advanced Auditory-Verbal Therapy" - Donald Goldberg, Ph.D.
- "Cochlear Implants: Creating Supportive Educational Environments" - Cheryl DeConde Johnson, Ed.D., and Leeanne Seaver
- "How to Read a Cochlear Implant Map" - Dawn Dawsey and Jill Chinnici
- "Wireless Communication for People with Hearing Loss" - Judy Harkins, Ph.D. and Karen Peltz Strauss, J.D.
- "English as a Second Language for Students with Hearing Loss" - Panel Discussion with Audience Participation
- "Ready, Set, Go! Creating a Successful Mainstream Experience for Preschoolers with Hearing Loss" - Maura Berndsen
- "Cued Speech Kids: A Parent/Teacher Panel" -Moderator: Maria Gildea
- "College Survival 101" - Rachel Arfa
- "The ADA and You: Rights and Responsibilities" - Robin Deykes, J.D.
- "Teaching Children Who are Deaf and Hard of Hearing to Talk" - Jean Sachar Moog and Betsy Moog Brooks

For a complete listing of educational sessions and registration information, please visit our website at www.agbell.org or contact AG Bell at 202/337-5220.

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Volume 101, Number 5

Alexander Graham Bell Association for the Deaf and Hard of Hearing

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Donna L. Sorkin, Executive Director

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The Volta Review is devoted to the reporting of scholarly findings in areas related to hearing loss and to the balanced coverage of those issues, regardless of educational philosophy.

The Volta Review

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Organized in 1890 to encourage the teaching of speech, speechreading, and the use of residual hearing to people who are deaf or hard of hearing, the Alexander Graham Bell Association for the Deaf and Hard of Hearing welcomes to its membership all who are interested in improving educational, professional, and vocational opportunities for people who are deaf or hard of hearing. Affiliated with AG Bell are the Parents' Section (PS), the Deaf and Hard of Hearing Section (DHHS), and the International Professional Section (INPROSEC).

Classroom Acoustics: Understanding Barriers to Learning

Foreword

Donna L. Sorkin, M.C.P., Executive Director,
Alexander Graham Bell Association for the Deaf and
Hard of Hearing

Introduction

Although many audiologists, educators, and acoustical engineers have recommended for some time the need to improve the acoustical environment in the classroom, advocates for children have had no effective mechanisms to successfully implement the needed changes. For example, in the United States there are currently no acoustical performance or testing standards for the classroom, and the fact that neither the federal government nor the American National Standards Institute (ANSI) — this country's official standards-setting body — has adopted a standard has made it very difficult for parents of children with hearing loss to convince their local schools to undertake acoustical improvements in the classroom. Fortunately, because of the continuing efforts of parents, audiologists, acoustical engineers and consultants, educators, architects, and others, it is now likely that such standards will be formally adopted in the near future.

The existence of acoustical standards would increase the likelihood that new or renovated construction would incorporate favorable acoustics. Once a standard is adopted by ANSI, it is expected that a proposal will be made to the International Code Council to include the recommended provisions as part of the International Building Code 2002 Supplement. This process would help to ensure that an acoustical standard was adopted as part of local building codes and would provide an enforceable mechanism to improve the listening environment for all children in the future. An adopted standard also would make it easier for parents to attain acoustical improvements as part of their child's individualized education plan (IEP).

Lack of Legal Mechanisms to Implement Acoustical Improvements

Members of the Alexander Graham Bell Association for the Deaf and Hard of Hearing (AG Bell) have long recognized the need for providing an appropriate acoustical environment for children who are deaf or hard of hearing. Parent members have communicated, with considerable frustration, their efforts to convince school officials that poor acoustics are a barrier for their child — just as a flight of stairs is a barrier for a child in a wheelchair. Efforts to gain acousti-

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Donna Sorkin is the executive director of the Alexander Graham Bell Association for the Deaf and the Hard of Hearing. She worked as a city planner before becoming involved full time in education and advocacy for people with hearing loss in 1993.

cal improvements have been stymied because inappropriate acoustics are not as obvious as physical obstacles. Further, it has been difficult to define what constitutes suitable acoustics. Although some parents have been successful in their efforts to have their child's classroom carpeted, for example, it generally takes a tenacious individual with strong advocacy skills to overcome the resistance typically encountered from school administrators.

Lack of Knowledge Among Architects

A major problem facing advocates is that the study of acoustics infrequently makes its way into the architecture curriculum. Consequently, acoustical issues are rarely considered in building design. Indeed, many architects have limited knowledge of how to improve the acoustical quality of the built environment. At a recent Access Board public hearing on accessability in public schools, an architect working for a local school district proudly described his efforts to ensure access for children with disabilities. When asked what was being done in the way of classroom acoustics, the architect replied that though the acoustics in the gymnasiums of most schools were probably poor, there were no problems with the acoustical quality of the regular classrooms. Also present at that hearing was a teacher of children who are deaf or hard of hearing from the same school district, who later commented that the acoustics in her classroom were indeed a significant listening impediment for her students. The incident poignantly demonstrated the discrepancy between perceptions and reality among many people who are in a position to impact the listening environment of school buildings, such as the architect who was ostensibly knowledgeable about access for people with disabilities.

The *Americans with Disabilities Act* and Acoustics

When the *Americans with Disabilities Act* was passed in 1990, its principal aim was to make public places accessible to people with disabilities. The Access Board, a federal agency whose mission is to ensure accessibility for people with disabilities, was given responsibility by Congress for developing ADA Accessibility Guidelines. Although school buildings are covered by the ADA, the guidelines do not address acoustical issues (either in schools or in any other building type). Further, since classroom acoustics are generally not a part of local building codes, there has never been a formal mechanism for addressing classroom acoustics.

In recent years, a number of organizations with an interest in classroom acoustics — including AG Bell — urged the Access Board to address listening conditions in the classroom. These organizations have informed the Board that poor acoustics exclude people with hearing loss the same way physical barriers, such as a narrow door or a flight of steps, preclude access for people in wheelchairs. In April 1997, the timely petition to the Board by a parent of a child with hearing loss coincided with collaborative efforts by several organi-

zations urging the Access Board to address acoustics in its ADA revisions — efforts that also attracted the interest and support of several Board members. Audiologists and acoustical engineers began collaborating in this endeavor.

On June 1, 1998, the Access Board published a Request for Information (a notice) in the *Federal Register* to collect public comments on classroom acoustics. The notice asked commenters to indicate whether acoustic guidelines should be developed for various school settings (i.e., classrooms, gymnasiums, cafeterias), whether adoption of a standard would assist during the IEP process, what acoustical standards would be appropriate for classrooms used by children with hearing loss, and whether the Access Board should initiate a course of action relating to classroom acoustics. Approximately 100 comments were submitted by individuals and organizations, with the majority coming from parents of children with hearing loss and professionals in the field of audiology and acoustics. Commenters noted the serious difficulties their children or clients faced with existing classroom conditions and requested that the Access Board pursue a rulemaking on acoustics. Not surprisingly, few comments were received from school systems — the entities with the power to put these changes into effect but who generally have not responded to parental requests in the past.

Based on the comments received, the Access Board voted in March of 1999 to support an ongoing effort by the Acoustical Society of America (ASA) to develop a technical standard that could then be adopted by ANSI. The Board approved financial support for the ASA Working Group on Classroom Acoustics to ensure that a diverse group representing parents, adults with hearing loss, educators, audiologists, architects, and engineers could participate in the standard-setting process. The Board also indicated that it would work to ensure the adoption and enforceability of a standard for acoustics if it found the ANSI standard acceptable. This action by the Board provided interested parties with the mechanism needed to implement an acoustical standard. Further, the support encouraged the various groups (i.e., engineers, audiologists, architects, parents) to seek common ground and collaborate.

A draft standard developed by the ANSI/ASA Working Group on Classroom Acoustics has been sent for ballot to the ANSI Committee S-12 on Noise. If adopted, the Access Board has committed to pursue its enforceability. The Board voted at its March 2001 meeting to submit proposed revisions to the International Building Code (IBC) for inclusion of the standard in the 2002 Supplement to the IBC. Another vehicle that could ensure widespread usage of the standard would be a reference in the U.S. Department of Education regulations covering federal assistance to local public schools.

If so referenced in the building code, classroom acoustics guidelines would impact new and renovated schools — a marvelous gift to children in the future. But such codes do not require existing structures to adopt such features. So, what about children in schools that are already in place and not slated for major renovations? How will this effort help those children who need help right now?

Many advocates believe that simply having a widely adopted standard in place will help a parent seeking acoustical improvements for his or her child under the *Individuals with Disabilities Education Act* (IDEA). To respond to

requests for guidance now, the Access Board published in 1999 a "Notice of Agency Action on Acoustics Standards" in the *Federal Register.* This notice provides public guidance, for the first time, on specific criteria for acoustics in the classroom. These recommendations are drawn from accepted practice and from the American Speech-Language-Hearing Association (ASHA) "Acoustics in Educational Settings" position statement published in March 1995. The ASHA guidelines recommend that:

- Unoccupied classroom noise levels should not exceed 30 dB(A).
- Signal-to-noise ratios (SNRs) at the student's ear should exceed a minimum of +15 dB.
- Reverberation times (RTs) should not exceed 0.4 seconds.

Although the final adopted ANSI standard might vary from the guidelines above, those involved in the process agree that the variance will likely not be great and that it is important to provide assistance in the interim period to those involved to ensure that children receive the appropriate accommodations under the IDEA. We've already seen how important it is to move quickly on this issue. New school construction was a high priority for the Clinton Administration; with major initiatives under way for new school construction throughout the United States, guidance on acoustics was needed immediately. There has been an increase in funding availability for school construction and renovation across the country, and the Bush Administration has also shown a continued interest in educational issues.

Future Prospects for Classroom Acoustics

The AG Bell membership has long urged for greater emphasis on the acoustical environment in schools. The attention now being given to the quality of classroom acoustics by the ASA's Working Group (in which AG Bell is an active participant) and by the Access Board (on which the author serves as a board member) will aid parents, professionals, and adults who are deaf or hard of hearing who wish to press for an improved acoustical environment in their local schools. Many advocates hope that these efforts to address classroom acoustics will be expanded to address building environments in general, not just learning spaces for students. The listening needs of children in schools are critical, but poor acoustics are also a barrier to adults with hearing loss whenever they gather to exchange information and wherever listening is integral to the use of a room. This includes theaters, auditoriums, conference rooms in private offices and government buildings, and colleges and universities. After all, we want our children who are deaf or hard of hearing to succeed in college, in the workplace, and wherever they are communicating with others in the mainstream of society. Indeed, ensuring that building environments permit full inclusion, regardless of disability, is what advocates for the ADA had in mind when this legislation was passed in 1990.

With these considerations in mind, this monograph issue of *The Volta Review* will examine from various perspectives the importance of appropriate acoustics in the educational environment. This issue, under the aegis of special editors Carl C. Crandell, Ph.D., and Joseph J. Smaldino, Ph.D., was written to be pertinent to many groups, including parents, adults with hearing loss, audiologists, teachers of the deaf, speech-language pathologists, architects, and acoustical engineers.

References and Resources

The Access Board — www.accessboard.gov/rules/acoustics.html

Acoustical Society of America — www.acoustics.org/133rd/lay_lang.html

Acoustics Standards Update — www.edfacilities.org/ir/acoustics.html

AG Bell – www.agbell.org

American Speech-Language-Hearing Association (1995, March). Position Statement and Guidelines for Acoustics in Educational Settings. *ASHA, 37*(Suppl. 14), 15.

1 Classroom Acoustics: An Overview

Fred H. Bess, Ph.D.

This chapter provides a general overview of the importance of classroom acoustics on the learning potential of children with hearing loss and related disabilities. Specifically, the chapter examines some of the early seminal research on classroom acoustics and suggests implications for education. It also calls for the development of standards to promote acceptable acoustical environments.

Introduction

> *"One of the main tasks of those who are responsible for the education of most deaf children is to help them to get maximum benefit from the use of hearing aids, and this task does not end when a child has been given an aid and switched it on. Parents, administrators, and teachers need to recognize the acoustic problems which can arise when aids are used and to ensure, as far as possible, conditions which allow them to be used efficiently. . . . Nevertheless, it is a sad fact that in a great number of schools little or nothing is done about room acoustics; in such conditions, hearing aids cannot be used efficiently."*
>
> J.E.J. John
> *Acoustics and Efficiency in the Use of Hearing Aids* (1957)

With those words, penned more than four decades ago, J.E.J. John addressed the importance of the acoustic environment for the young child with hearing loss. He clearly illustrated what we now know quite well about the adverse effects of room acoustics: that amplification systems must deliver speech at a favorable signal-to-noise ratio (SNR) and at a sufficiently loud level if the message is to be clearly understood. Unfortunately, the ambient noise and reverberation levels in classrooms are often far too high to produce what we consider an appropriate SNR. This is compounded by the fact that children with hearing loss exhibit greater difficulty in understanding speech than children with normal hearing under the same noise and reverberant conditions.

Other factors that contribute to an adverse listening situation for young children with hearing loss include speaker-listener distance; the degree, configura-

Fred Bess is a professor and chair of the Department of Hearing and Speech Sciences, Vanderbilt Bill Wilkerson Center for Otolaryngology and Communication Sciences, Vanderbilt University Medical Center, Nashville, TN.

tion, and type of hearing loss; type of amplification; the child's age and linguistic abilities; the complexity of the message; and classroom lighting. Indeed, the poor acoustic properties of the classroom may be another contributing factor to the many failures we have experienced in our attempts to educate children with hearing loss. This chapter recognizes the general importance of the classroom environment to the learning potential of a child with hearing loss and/or related disabilities. To this end, this chapter provides an overview of some of the early seminal research on classroom acoustics, suggests implications for education, and calls for the development of standards to promote acceptable noise and reverberation levels in all learning environments.

Classroom Noise

Noise within the classroom can originate from several different sources: sounds generated outside the building (external noise sources), sounds generated within the school but outside the classroom (internal noise sources), and sounds created within the classroom (classroom noise sources) (Olsen, 1977). Street traffic, air traffic, and construction noise are examples of external noise sources. Internal noise can be generated from various sources, such as ventilation and heating systems, toilets, workshop and craft rooms, music rooms, kitchens, dining rooms, adjacent classrooms, and hallways. Classroom noise evolves from normal class activities and includes talking, shuffling feet, and paper noise.

Classrooms for children with hearing loss can be divided into two general categories (Fourcin, Joy, Kennedy, Knight, Knowles, Knox, Martin, Mort, Penton, Poole, Powell, & Watson, 1980). In what are known as Type 1 classrooms, children develop special skills such as art and crafts or physical education. Although these rooms are used less frequently than regular classrooms, children do spend a certain percentage of each day in these areas with their hearing aids. The second category, designated as Type 2, refers to classrooms in which children spend the greatest amount of time and in which the effective use of the hearing aid is most important for learning.

What, however, are considered acceptable noise levels for each of these classrooms used by children with hearing loss? According to Fourcin et al. (1980), classroom noise levels in Type 1 areas should be limited to 45 dB(A) or less; in Type 2 areas, noise levels should not exceed 30–35 dB(A). Although only limited data are available on the noise levels in Type 1 areas, we can assume that the values will run slightly higher than those found in Type 2 areas. Several studies have shown that typical noise levels in Type 2 classrooms far exceed the suggested criteria of 30–35 dB(A). One of the earliest studies on classroom acoustics sampled noise levels in 47 classrooms representing 15 different schools (Sanders, 1965). Mean noise values for kindergarten classes were highest at 69 dB, followed by high school, elementary, and special units for students with hearing loss. The highest noise levels were measured in the kindergarten classes where basic fundamental concepts are learned. Sanders (1965) noted that the observed noise levels reduced the ratio of the intensity of the teacher's voice to the intensity of the

room noise (at the child's ear) to an average of +5 dB in the high school rooms and +6 dB in the lower grade rooms.

Because of the increased awareness of the importance of noise levels in the classroom and greater knowledge about noise reduction techniques, one would assume that today's classrooms for children with hearing loss would be somewhat quieter than those in the Sanders (1965) study. Unfortunately, this is not the case. Current reports demonstrate that modern classrooms occupied by children with hearing loss exhibit noise levels that far exceed the basic recommendations made by Fourcin et al. (1980). That is, occupied noise levels continue to hover around 55 dB–60 dB. Clearly, audiologists, educators, and school administrators need to place greater emphasis on the classroom environment if optimal listening conditions are to be achieved.

Importance of the Signal-to-Noise Ratio

According to Ross, "the most important consideration for speech intelligibility is not the absolute noise level existing in classrooms, but rather the intensity ratio at the child's ear (or hearing aid microphone) between the teacher's voice and the ambient noise" (Ross, 1978). Listeners with hearing loss need SNRs of +20 dB–+30 dB for optimal speech understanding — that is, the signal is 20 dB–30 dB louder than the background noise (Gengel, 1971; Olsen 1977). These values are somewhat higher than those required for the person with normal hearing because children with hearing loss perform more poorly than children with normal hearing under identical noise conditions.

The most important factor in determining the SNR is the distance between the speaker and the listener. According to the inverse square law,[1] sound pressure decreases by 6 dB when the distance between the speaker and the listener is doubled. Thus, if the sound pressure of a signal is 70 dB at 2 feet, it will be 64 dB at 4 feet, 58 dB at 8 feet, and 52 dB at 16 feet. The SNR will become less favorable as the speaker–listener distance increases.

By applying this concept to the classroom noise reported by previous investigators, it is possible to determine the SNRs as a function of distance. Based on data by Lybarger (1979), the average speech intensity at 3 feet is 65 dB SPL. Given that the average classroom has a noise level of 56 dB(A), the speech will reach the child's ear at an intensity 9 dB greater than the noise (65 dB - 56 dB = +9 dB SNR). At 6 feet, the intensity of the speech signal will decrease 6 dB (65 dB - 6 dB) and the SNR will only be +3 dB (59 dB - 56 dB = +3 dB SNR). Finally, at a distance of 12 feet, the intensity of the speech signal will decrease by another 6 dB (65 dB - 12 dB), leaving the SNR at -3 dB (53 dB - 56 dB = -3 dB SNR). Hence, it is advisable for audiologists and teachers to determine estimates of the SNRs at various distances for classrooms within their schools.

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[1]The inverse square law in solid geometry states that the intensity of a sound decreases inversely with the square of the distance from the sound source.

Table I. Mean Percentage of Word Recognition Scores for a Group of Children with Normal Hearing and a Group of Children with Hearing Loss Under Various Signal-to-Noise Conditions*

Signal-to-Noise Ratio (dB)	*Mean Scores (Percent)*	
	Children with Normal Hearing	*Children with Hearing Loss*
Quiet	95	83
+12	89	70
+6	80	60
0	60	30

*Adapted from Finitzo-Hieber, T., and Tillman, T.W. (1978). Room acoustic effects on monosyllabic word discrimination ability for normal and hearing impaired children. *Journal of Speech and Hearing Research, 21,* 440-448.

Effects of Noise on Speech Understanding

As noted earlier, we have long recognized that children with hearing loss experience more difficulty understanding speech under a given noise condition than children with normal hearing. A seminal study in this area by Finitzo-Hieber and Tillman (1978) investigated speech recognition performance under noise conditions in a group of children with normal hearing and a group of children with either mild or moderate hearing losses. Data were collected in an anechoic chamber under monaural conditions — the children with normal hearing each wore a single earmuff and the children with hearing loss each wore an ear-level hearing aid. These data are summarized in Table I. As listening conditions worsened, the disparity between the scores of the children with hearing loss and those with normal hearing increased. In quiet conditions, there was a difference of 12% between the two groups; however, at a SNR of 0, the difference in speech recognition increased to 21%. Olsen (1977) reminds us that these data were collected under the most ideal conditions (i.e., anechoic chamber). Unlike an anechoic room, most classrooms have reflective surfaces that cause the sound waves to persist within a room. This concept is referred to as reverberation.

Interestingly, noise does not just affect individuals with severe-to-profound sensorineural hearing loss. Deleterious effects may also occur with children exhibiting minimal sensorineural hearing loss, unilateral sensorineural hearing loss, learning difficulties, auditory processing problems, and middle ear disease with effusion. Individuals learning in a second language may also be particularly affected.

Classroom Reverberation

Reverberation is the persistence of sound within an enclosed space when sound waves reflect off hard surfaces. A visual example of this concept is

shown in Figure 1. As sound waves (depicted by the heavy dark lines) are transmitted from the speaker, some of the waves strike the child's hearing aid directly without any interference from any objects within the room. Other sound waves, however, strike the floor, ceiling, and walls and are reflected back into the environment. When these reflected waves strike hard surfaces, they are once again reflected into the environment. This process continues until the sound waves are absorbed and/or the sound energy is dissipated. Thus, the initial sound wave is broken up into a multitude of sound waves arriving at the child's hearing aid at different times. The persistence of a sound within an enclosed space depends on the absorption capacity of the surface encountered by the sound wave. The harder and less absorbent the surface, the more persistent the sound wave.

In Figure 2, we illustrate the sound propagation when the surfaces exhibit maximum absorption in an anechoic chamber. When the original waves strike the highly absorbent surfaces of the anechoic room, no waves are reflected into the environment and, thus, there is no reverberation.

The distribution of sound within an enclosed space is an important factor. As the speech signal is emitted, the repetitions of the sound waves are disseminated uniformly throughout the room so that there is equal distribution of energy. The intensity of the sound within an enclosed space depends on the room's absorption characteristics. Demonstrated in Figure 3 is the relationship between different amounts of acoustic treatment for three otherwise equivalent rooms and the sound pressure level of an identical sound source at varying distances. The intensity of a direct sound path predicted by the inverse square law with no interference of the sound wave is also provided for comparison. Each room, beginning with Room A, has progressively more acoustic treatment for sound — as the distance from the speaker increases, the sound pressure decreases. Beyond 2 feet, however, sound energy increases irrespective of the distance as the reverberant characteristics of the room increase. In Room A, for example, a slight decrease in sound pressure from 2 to 4 feet is followed by stabilization of sound energy. Thus, the highly reflective surfaces within the room cause an increase in sound pressure. With the possible exception of an anechoic chamber, all rooms exhibit some degree of reverberation. Reverberation time can be described as the amount of time required for sound to decrease by 60 dB following termination of the signal. The human ear can integrate repetitive sounds that arrive up to 0.08 seconds after the original sound wave has terminated. In fact, it is believed that waves reflected at an interval of 0.02–0.03 seconds serve to enhance speech understanding in the normal auditory system, but this is not true for listeners with hearing loss.

What is considered a reasonable reverberation time for the average classroom? Ross (1978) indicated that the most appropriate reverberation time is the time that yields the best speech understanding. Ross also noted that smaller rooms have shorter reverberation times than larger rooms because they yield many more reflections from the same sound wave and create a masking effect. For normal listeners, the ideal reverberation time is believed

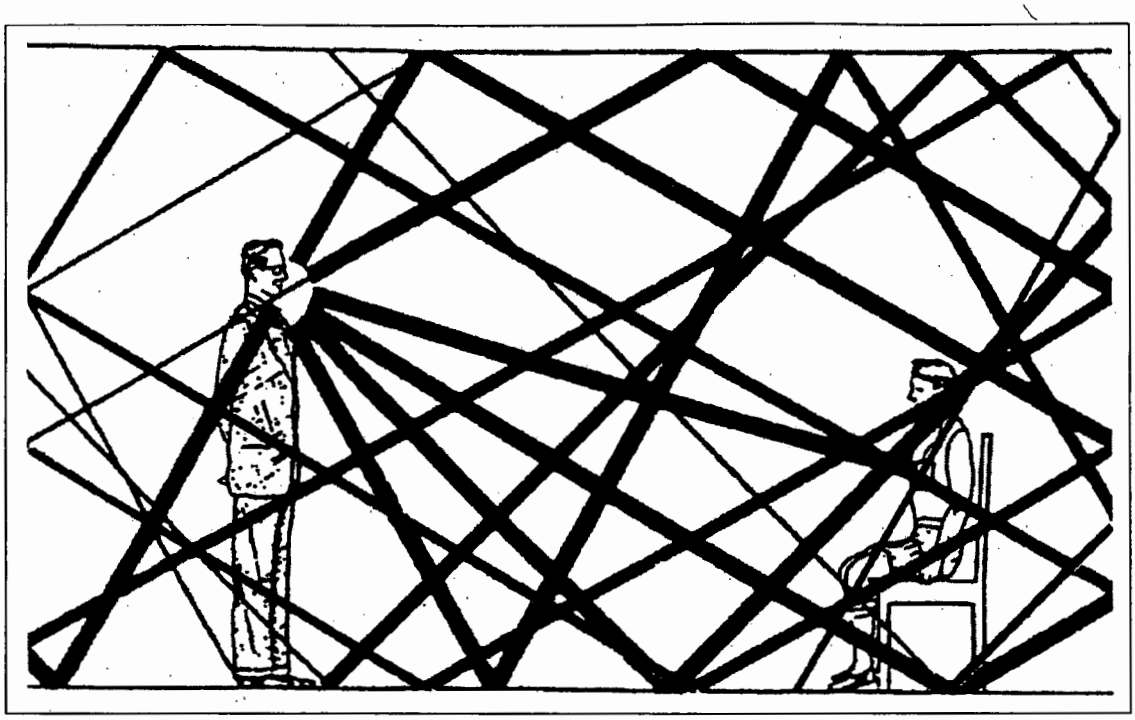

Figure 1. A visual example of reverberation.

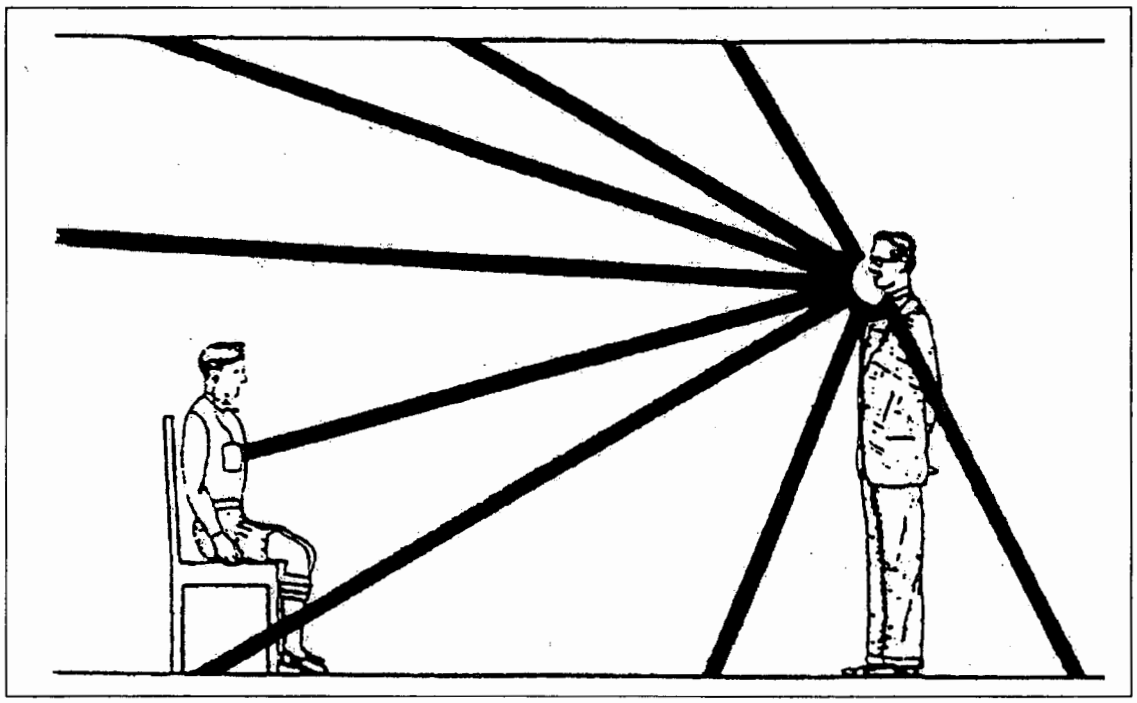

Figure 2. An example of sound propagation when room services exhibit maximum absorption, such as in an anechoic chamber.

to be between 0.6 and 0.8 seconds for larger classrooms and 0.4 seconds for smaller rooms. Children with hearing loss, however, experience far greater difficulty for the same reverberation time than their peers with normal hear-

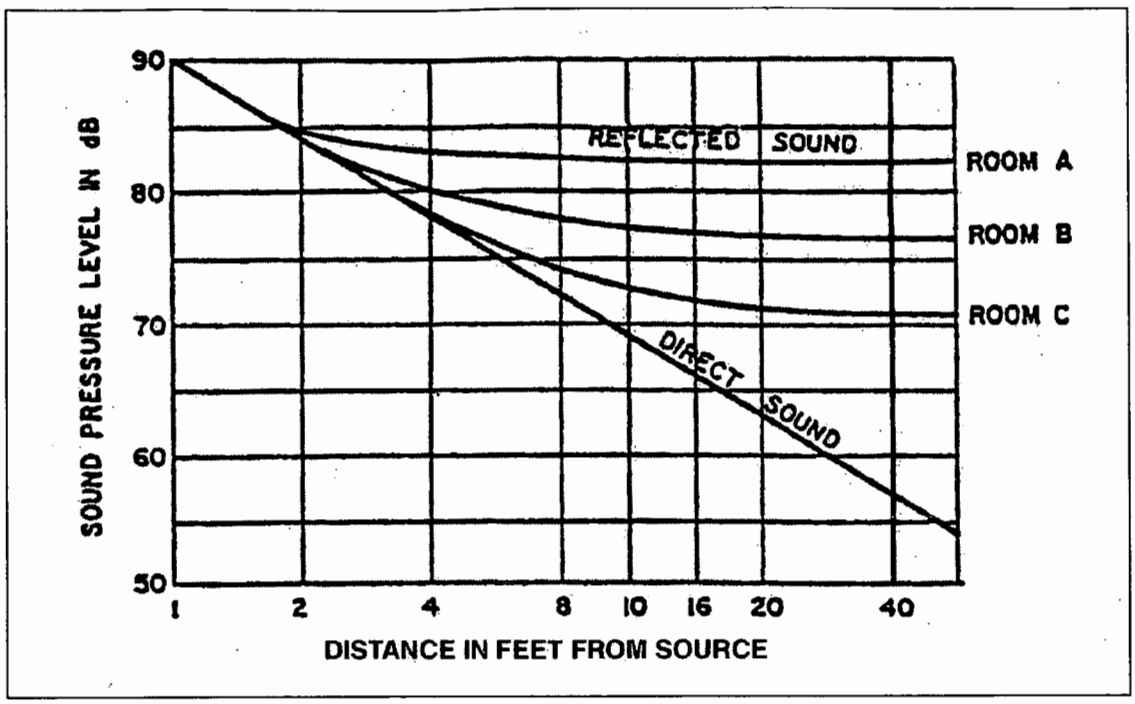

Figure 3. The relationship between different amounts of acoustic treatment for three otherwise equivalent rooms at varying differences.

ing. Thus, what is considered ideal for listeners with normal hearing may be far too adverse for children with hearing loss. Unfortunately, we find that typical reverberation times exhibited within classrooms far exceed any minimal standard. In Table II, the range of reverberation times from various classrooms is illustrated. Clearly, reverberation times within these classrooms will cause difficulty for children with hearing loss.

Classroom Reverberation and Understanding

Reverberation is an important determinant of speech understanding. Several studies have demonstrated that reverberation can cause difficulty in speech understanding for normal listeners and can create even greater problems for individuals with hearing loss. An example of how a child with hearing loss copes with reverberation is shown in Table III. This table, adapted from data provided by Finitzo-Hieber and Tillman (1978), represents the word recognition scores under varying reverberant conditions for children with normal hearing and children with hearing loss who use hearing aids. The children with normal hearing showed essentially no change in reacting to reverberation time from 0.0 seconds to 0.4 seconds, but there was some degradation in speech understanding at the reverberation time of 1.2 seconds. Note, however, that children with hearing loss experienced considerably more difficulty with the reverberation conditions. Note also that the difference between the two groups in the nonreverberant condition is only 12%,

Table II. Reverberation Times for Several Different Classrooms*

School	*Classroom Area (square feet)*	*Classroom Shape*	*Seating Capacity*	*Description of Interior Finishes*	*Classroom Occupied Reverberation Time at 1000 Hz (seconds)*
1	765	Hexagonal; CH	28	AC tile on 15% of ceiling; tackboard on some wall surfaces	1.0
2	782	Rectangular	33	Painted CB on walls; insulation board on ceiling	0.5
3	1085	Almost Square	35	5/8-inch AC tile on ceiling	0.4
4	880	Rectangular	28	CB on walls; no AC tile on ceiling	1.0
5	1130	Rectangular	38	Reflective walls and ceiling except 288-sq. ft. AC tile	1.1
6	694	Rectangular	38	3 walls CB; plaster ceiling	0.7
7	847	Rectangular	31	Reflective walls; AC tile over entire ceiling	0.45
8	857	Rectangular	36	CB walls and ceiling	0.45
9	830	Rectangular; CH	34	Plaster walls; AC plastic ceiling varies	0.8
10	936	Rectangular	32	Plaster walls; AC tile ceiling	0.5
11	860	Rectangular	39	CB walls; AC tile ceiling	0.4

*Adapted from Kodaras, M.J. (1960). Reverberation times of typical elementary school classrooms. *Noise Control, 6*, 17-19.

Legend: CH = Ceiling height above the floor; AC = acoustic; CB = cinder block, usually a local product with large variation in acoustic absorptivity; Insulation Board = 1/2-inch or 3/4-inch insulation board ceiling squares on wood furring with no perforations and no rated values.

Table III. Mean Word Recognition Scores Under Varying Reverberant Conditions for a Group of Children with Normal Hearing and a Group of Children with Hearing Loss Wearing Hearing Aids*

Reverberation Time (seconds)	*Word Recognition Scores (percent)*	
	Children with Normal Hearing	*Children with Hearing Loss*
0.0 (nonreverberant)	95	83
0.4	93	74
1.2	77	45

*Adapted from Finitzo-Hieber, T., and Tillman, T.W. (1978). Room acoustic effects on monosyllabic word discrimination ability for normal and hearing impaired children. *Journal of Speech and Hearing Research, 21,* 440-448.

Table IV. Mean Word Recognition Scores for a Group of Children with Hearing Loss Wearing Hearing Aids Under Various Noise Reverberant Conditions*

Reverberation Time (seconds)	*Signal-to-Noise Ratio (dB)*			
	Quiet	*+12*	*+6*	*0*
0.0 (nonreverberant)	83	70	60	39
0.4	74	60	52	28
1.2	45	41	27	11

*Adapted from Finitzo-Hieber, T., and Tillman, T.W. (1978). Room acoustic effects on monosyllabic word discrimination ability for normal and hearing impaired children. *Journal of Speech and Hearing Research, 21,* 440-448.

whereas in the two reverberant conditions the differences increase to 19% and 32%, respectively. Hence, children with hearing loss exhibit far greater difficulty understanding speech in different reverberant conditions than children with normal hearing.

Combined Effects of Noise and Reverberation

We have discussed noise and reverberation as separate entities as though they were independent of each another. Actually, the combined effects of noise and reverberation serve as a competing background for children with hearing loss. As Olsen noted, "the combination of all such noises together with the reverberant conditions of some classrooms, results in a variable cacophony of sounds within the room" (Olsen, 1977).

Since noise and reverberation are each known to affect speech understanding deleteriously, it is not surprising that when combined the two factors cause an even greater disruption in speech recognition. The breakdown

effects of noise and reverberation on speech understanding are demonstrated in Table IV. These data, again taken from the classic study by Finitzo-Hieber and Tillman (1978), represent the mean word recognition scores of children with hearing loss wearing hearing aids under various noise and reverberant conditions. As shown, word recognition is further reduced when reverberation and noise are combined. At an SNR of +6 (considered a common listening condition in a classroom setting), with a reverberation time of 0.4 seconds, the mean word recognition score is 52%. When reverberation time is 1.2 seconds, speech recognition is only 27%. Thus, a child with a hearing loss experiences considerable difficulty trying to learn under these adverse conditions. Unfortunately, it is quite common to have classrooms with SNRs of +6 and reverberation times of 1.2 seconds.

Classroom Acoustics and Listening Effort

Children with hearing loss not only experience difficulty understanding speech under adverse listening conditions, but they also expend a great deal of effort in attending to the spoken message (Ross, 1992). Studies have demonstrated that not only does the presence of noise increase learning effort, it even reduces the energy available for performing other cognitive functions (Rabbit, 1966; Downs & Crum, 1978). According to Bess, Dodd, and Parker (1998), young school-age children with minimal sensorineural hearing loss reported less energy or were tired more frequently than children with normal hearing. This finding may well be due to the difficulties these children experience listening under adverse noise/reverberant conditions. One can speculate that toward the end of a school day, children with hearing loss will be physically and mentally "spent" as a result of focusing so intently on the teacher's speech and on the conversations of other children. This effort will no doubt impact negatively on the child's facility to learn in the classroom.

Acoustical Modifications in the Classroom

Acoustical modifications in the classroom will be addressed briefly in this section, but the topic is discussed in detail elsewhere in this monograph. Because there are limitations for reducing external noise by altering the internal environment, the most effective means of noise control is to prevent sound from entering the classroom. It is important that all new facilities use appropriate design and construction techniques to alleviate external noise. Site selection is a vital concern, and high environmental noise levels must be avoided. External (environmental) noise levels of 55 dB(A) require no special noise reduction techniques, but as values increase above this intensity more extensive noise reduction procedures are needed. The best approach to reduce noise is to select construction materials with high mass per unit square area and to use double-walled construction with airspace between (Fourcin et al., 1980). The quality of construction is of prime importance in noise reduc-

tion — for example, mortar must fill gaps between bricks, with no minor cracks or openings that might result in noise leakage.

Olsen (1977, 1988) writes that several approaches can be used to reduce external and internal noise. A room with solid outside walls usually absorbs external noise better than one with many windows because windows are poor sound insulators. However, if windows are necessary, double panes are preferred; each pane should be of different weight and placed in a separate frame. A double-pane window with an 8-inch airspace will provide an average attenuation (at 100 Hz–3200 Hz) of 17 dB more than the amount offered by a single glass pane (Fourcin et al., 1980). This large difference in attenuation characteristics can significantly affect the SNR that reaches the child's ear.

Landscaping can also serve as a buffer from unwanted external sounds. Grass-covered hills or earthen banks and evergreens or shrubs, placed between the noise source and the facility, provide interference and absorption of the noise. Strategic arrangement and design of the facility and selection of a classroom away from outside noise sources can also help reduce the amount of external noise.

To control internal noise, Fourcin et al. (1980) recommend the following:

1. Increase the distance between the teaching area and the noise source.
2. Interpose non-teaching areas or dead space between the noise source and the teaching area (e.g., storage rooms, corridors, and libraries). Avoid long, straight corridors and treat corridors with carpet.

Several other techniques can prevent noise from entering the classroom. Consideration should be given to the use of acoustically treated double doors with good tight seals, the use of double glazing for sound absorption, increasing the thickness of the walls, and structural isolation where appropriate (Fourcin et al., 1980).

Other techniques also help reduce noise within the classroom. Carpeting helps to absorb classroom noises such as shuffling of feet, movement of desks, and interference created by objects striking a floor with a hard surface. If carpeting cannot be used, desk and chair legs can be covered with felt or rubber (Olsen, 1977, 1988). Heavy draperies, especially if set at a slight distance from the wall, also can serve to absorb unwanted sound. Other helpful options include fastening chalkboards or blackboards securely to the wall, hanging acoustic tile on the walls, and using quieter heating and air circulation equipment.

Implications for Education

Efforts to provide appropriate remediation for children with hearing loss will be futile if we do not improve classroom acoustics. Audiologists and teachers must understand the importance of the signal-to-noise ratio and ensure that children with hearing loss function under favorable listening conditions. Every attempt must be made to reduce noise and reverberation to a minimum by using some of the suggestions discussed above. More important, however, is the need to maintain a short distance between the speaker and the listener in order to achieve a favorable SNR at the child's ear. Under ideal

classroom conditions, the speaker-listener distance should not exceed 6–8 feet, and the teacher should speak as closely as possible (6–8 inches) to the child's ear or hearing aid microphone (Olsen, 1977, 1988; Ross, 1992). Parents should also be counseled about the importance of the speaker-listener distance.

The increased emphasis on mainstreaming has made it more difficult to control acoustics within the classroom. Further, as Børrild (1978) has pointed out, the trend in education to make classrooms larger has created problems with sound distribution in the rooms. This problem is complicated by the fact that teachers no longer teach, as they formerly did, from an elevated platform. Consequently, the students sitting in the front of the class buffer the teacher's speech, causing a reduced signal at the back of the room. Special problems associated with room size also are created with the modern open-space schools. Small groupings of classes within a large open space cause considerable difficulty for the school-age child wearing a hearing aid. Børrild (1978) made the following recommendation when that condition exists:

> *The only possibility that remains to create acceptable acoustic conditions is to increase the area per student so that there will be room for greater distance between the groups, or to make the ground plan irregular with many nooks and corners and with passages between the instruction areas suitable for the creation of sound traps.*

Once every effort has been made to reduce the teacher-to-child distance and the noise/reverberation levels within the classroom, the use of amplification needs to be considered. A general rule of thumb is that if the reverberation time is less than 0.5 seconds and the SNR is greater than +15 dB, a conventional amplification system can be used. However, if the reverberation time is greater than 0.5 seconds or the SNR is less than +15 dB, FM technology in the form of the traditional FM system or sound-field amplification should be considered.

The Need for Standards

This review has demonstrated that the acoustical properties of educational settings are such that they compromise the potential for many children to learn. We have known for at least 40 years that noise and reverberation cause a significant breakdown in speech understanding, yet we continue to observe excessive noise/reverberation levels even in our most modern schools. There is an urgent need to develop a consensus-driven standard concerning noise and reverberation levels in classrooms and the acceptable SNRs to reach a child's ear. If we expect children to perform at their maximum potential in the schools, they must have appropriate classroom conditions. One could argue that our failure to ensure acceptable noise levels in classrooms for children with hearing loss creates barriers and compromises accessibility — a situation that violates the *Americans with Disabilities Act* (ADA). The development of appropriate guidelines for these children will no doubt be a first step in helping to ensure their success in schools.

Summary

Because of the high noise levels and reverberation times in classrooms used by children with hearing loss, there is an urgent need to give more serious consideration to the acoustic environment. Noise and reverberation can create significant problems in speech understanding and in listening effort. Our efforts to provide these young children with appropriate education will be futile if we do not improve classroom acoustics. Audiologists and educators alike must understand the importance of the SNR — we must strive to maintain a short distance between the speaker and the listener in order to achieve a favorable SNR at the child's ear. If one cannot achieve an appropriate SNR, the use of FM technology should be considered. Again, the need for standards or guidelines in room acoustics also should be emphasized.

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2 Speech Perception in the Classroom

Joseph J. Smaldino, Ph.D., and Carl C. Crandell, Ph.D.

It is well known that excessive background noise and reverberation can be a barrier to listening and learning in the classroom. The barriers exist because poor room acoustics can make speech inaudible and can distort information-carrying elements of the speech signal. A simple speech-perception model is presented which demonstrates the linkage between the adequacy of classroom acoustics and the development of a speech and language system. Both aspects must be considered when evaluating the potential barriers to listening and learning in a classroom.

Introduction

Sharing experiences, exchanging ideas, and transmitting knowledge are the primary goals of listening and learning in most classrooms. Students normally are able to accomplish these goals by accurately receiving specific acoustic speech information and by fitting the frequently ambiguous acoustic speech cues into a speech comprehension system (Denes & Pinson, 1993). A conceptual model of how a speech comprehension system might develop is shown in Figure 1. In this chapter, we will try to demonstrate the use of this model so the reader may better understand how classroom acoustics, language competency, and speech comprehension are linked, and how these linkages can be used to better understand the speech-comprehension performance of students with hearing loss.

Accurate speech comprehension is a developmental process. The process begins when an undistorted acoustic speech signal (and its component speech perceptual cues) induces in a child an organization of his or her neuronal and cognitive resources. The child then uses this organization (attention, memory, storage and retrieval, concept formation, etc.) to form an ever-expanding knowledge of speech and language and the surrounding acoustic world. As the knowledge base grows, more details and subtleties of the

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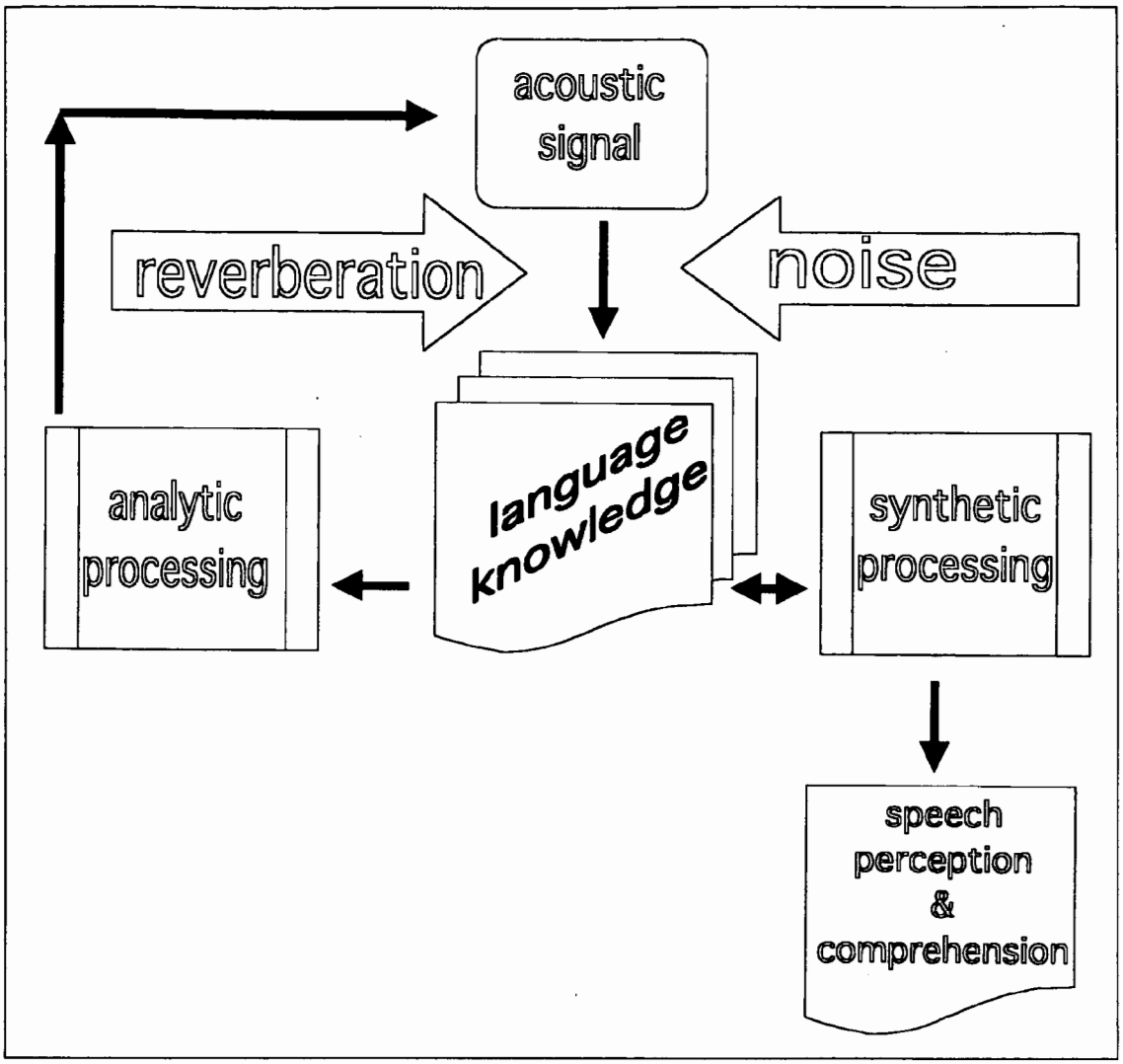

Figure 1. Conceptual model of speech comprehension.

acoustic signal become relevant and are available to be used to organize more complexity into a robust understanding of language. There is an important feedback loop in this process that demonstrates the interactive nature of a clear acoustic signal and the normal development of a functional speech and language system. However, though the language development process is so powerful that it occurs automatically in most children, the process can be made to malfunction. One malfunction might occur because the neuronal and/or cognitive resources available for the development process are inadequate. These children, who may be categorized as mentally retarded, behaviorally disordered, developmentally delayed, or as having a central auditory processing disorder, often develop inadequate speech and language systems which require intensive evaluation and therapy. Although the acoustic signal provides all of the necessary information for the developmental process to occur, the induction and organizational equipment is inadequate to use the information.

Another malfunction — the one we focus on in this chapter — is caused when the acoustic signal is distorted or otherwise inadequate. In this case, the induction and organization process will have incomplete data on which to structure a speech and language system. It has been long appreciated that children with hearing loss demonstrate this kind of malfunction of the process (Sanders, 1993). The hearing loss can affect the quality of the acoustic information in two ways. If the child has a simple loss of sensitivity, as might be seen in a conductive hearing loss, much of the important speech information will simply be inaudible, especially the low-intensity, high-frequency components which are known to carry most of the information. The induction and organizational processes can be mildly or severely compromised depending on the amount of hearing loss. If most of the information is audible, than perhaps only subtle aspects of the developing speech and language system will not be established. If the hearing loss is more severe, more information will be inaudible and significant aspects of the language acquisition process may be underdeveloped. If the child has a sensorineural hearing loss (SNHL), the informational signal may not only be inaudible, but also distorted by the impaired cochlea and/or auditory nerve, which define sensorineural hearing loss. The distortions may be in the areas of frequency, intensity, and/or time relationships in the informational signal. The impact of these distortions on the induction and organizational process might be mild if the distortions are few, or very significant if the distortions are many.

Another aspect of the model shown in Figure 1 is the processing mode. The speed with which a child can use the information arriving in the acoustic signal can be influenced by the developmental completeness of the speech and language knowledge established by the induction and organization process. To help the reader understand the importance of language competency, we will consider the example of a student learning a foreign language. When a student first begins to learn another language, he or she has an incomplete knowledge of the language and its associated articulatory, linguistic, and semantic cues. This incomplete knowledge base means the student is forced to attend closely to individual acoustic, linguistic, and contextual elements in the acoustic speech signal. This mode of processing, referred to as analytic processing, is very slow and inefficient because a one-to-one matching of acoustic events with speech and language patterns is often required. Because of this analytic form of processing the acoustic signal, someone learning a foreign language processes the acoustic elements very slowly. He or she frequently falls behind in conversation and can get hopelessly lost in the fast oncoming stream of acoustic information.

Analytical processing is also highly susceptible to distortions in the acoustic signal. Because each element of the signal must be accurately analyzed, if an element is lost due to acoustic distortion (reverberation) or masking (background noise) the language knowledge is not robust enough to help the learner "fill in" the lost elements. As a result, accurate perception of the speech signal suffers. As the learner becomes more proficient in the foreign

language, he or she can incorporate the efficiencies wrought by knowledge of language and context. He or she no longer needs to attend to every acoustic, contextual, and linguistic event and can take advantage of incidental learning. Incidental learning is the learning that takes place automatically, without the student having to focus on the learning process, such as vocabulary development (Wigg & Semel, 1984). Most of the efficiency results from the student being able to shift from analytical processing to synthetic processing. Synthetic processing permits simultaneous recognition and integration of acoustic, linguistic, and contextual events. Acoustic elements no longer need to be processed individually — the student is able to process the language at conversational speeds. Synthetic processing is less susceptible to distortions in the acoustic signal, so the proficient learner can understand better in background noise and is better able to tolerate speech distortions.

Classroom acoustic characteristics can be so poor that elements of the acoustic speech signal often are inaudible (because of excessive speaker-listener distance), and/or covered up or masked by background noise, and/or the clarity of the speech signal is compromised because of reverberation. It can be seen from the model in Figure 1 that these acoustic characteristics (shown as reverberation and noise in the model) can act as a barrier to the normal development of speech and language knowledge and lead to speech comprehension problems. Background noise acts as a barrier because it can mask and make inaudible the highly redundant acoustic and linguistic cues that form the basis for knowledge about speech and language. Reverberation acts as a barrier when the acoustic and linguistic cues of a speaker bounce off the ceiling, walls, and floor and interfere with the original speech signal. The interference covers up important acoustic and linguistic cues in the original signal. Taken together, noise and reverberation serve to degrade the input signal, making it harder for a child to induce and organize a proper speech and language knowledge. Poor room acoustics force the child to use a processing mode that is analytic rather than synthetic.

The magnitude of the problems that can be created by classroom acoustic barriers can be demonstrated in data collected by Finitzo-Hieber and Tillman (1978), shown in Table I. Reverberation time and message-to-competition ratio were covaried to form undistorted (RT = 0.0 sec; MCR = +12 dB) to distorted (RT = 1.2 sec; MCR = 0 dB) listening conditions. This range of listening conditions has been shown to be representative of conditions commonly encountered in classrooms (Crandell, Smaldino, & Flexer, 1995). As can be seen, children with normal hearing, who presumably had a normally developed knowledge of language, obtained relatively high speech-perception scores in the undistorted and mildly distorted listening conditions (percent monosyllabic discrimination scores in the 89.2–79.7 range) but showed a noticeable drop in percent speech-recognition scores as the signal became more distorted (in the worst condition allowing a score of only 29.7%). Children with hearing loss, who presumably had an imperfect knowledge of language, showed a poorer performance in the best conditions (percent

Table I. Mean speech recognition scores (% correct) by children with normal hearing (n = 12) and children with sensorineural hearing loss (n = 12) for monosyllabic words across various signal-to-noise ratios (SNRs) and reverberation times (RTs)*

	Groups	
Testing Condition	*Children w/ Normal Hearing*	*Children w/ Hearing Loss*
RT = 0.0 Seconds		
QUIET	94.5	83.0
+12 dB	89.2	70.0
+6 dB	79.7	59.5
0 dB	60.2	39.0
RT = 1.2 Seconds		
QUIET	92.5	74.0
+12dB	82.8	602
+6 dB	71.3	52.2
0 dB	47.7	27.8
RT = 1.2 Seconds		
QUIET	76.5	45.0
+12 dB	68.8	41.2
+6 dB	54.2	27.0
0 dB	29.7	11.2

*Adapted from Finitzo-Hieber, T., & Tillman, T.W. (1978). Room acoustic effects on monosyllabic word discrimination ability for normal hearing and hearing impaired children. *Journal of Speech and Hearing Research, 21,* 440-458.

scores in the 77.8–65.7 range), then a steeper drop in speech-recognition ability (in the worst condition only getting 11.2% correct). Although not shown in Table I, perception scores were even lower when the children listened through a hearing aid, which presumably further distorted the speech signal.

Even if the student is successful in integrating distorted acoustic and linguistic information into their knowledge of language, the knowledge itself may be faulty and produce long-term speech-perceptual problems. An example of this might be faulty development of phonics. Since phonics is known to be a prerequisite for learning how to read, the student's reading ability may be impaired and might affect academic performance of the student for years. Important to remember is the realization that while accurate reception of acoustic speech cues is critical for speech perception and comprehension to occur, so is a working knowledge of language and context. In other words, we

Table II. Populations of children with "normal hearing" who may be affected by poor room acoustics

- Young Children (less than 15 years)
- Conductive Hearing Loss
- History of *Otitis Media*
- Articulation and/or Language Disorders
- Learning Disabled
- Non-Native English
- (Central) Auditory Processing Deficits
- Minimal, or Borderline, Degrees of SNHL (16–25 dB HL)
- Unilateral Hearing Loss
- Developmental Delays
- Attention Deficits
- Reading Deficits (Dyslexia)

should be advocates of good acoustics and the removal of acoustic barriers to listening and learning (after all, you cannot process what you cannot hear), but professionals in audiology and acoustics should not ignore the barriers that incomplete language knowledge imposes on speech perception and comprehension. Many of the student populations at risk for listening and learning problems in the classroom are "at risk" because of the interaction of poor acoustics and inadequate knowledge of language and context. A list of these at-risk populations is shown in Table II.

Summary

As was stated above, the primary goal of the classroom educational process is to share experiences, exchange ideas, and transmit knowledge. The students accomplish this goal not only because they are able to receive specific acoustic information, but also because they are able to relate these often-ambiguous cues within the context of a language structure. Not all acoustic information is specific enough and not all of the students' speech perceptual systems are complete enough to allow the educational process to occur uninterrupted. It behooves the professional to identify and improve acoustic problems caused by the classroom environment. However, it is equally important to determine any speech perceptual breakdowns that individual students may have when these students must interact with the acoustic signal in the classroom. These professionals should clinically intervene when possible.

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3 The Changing Demand for Improved Acoustics in Our Schools

Peggy Nelson, Ph.D.

The education of children with hearing loss has changed significantly in recent years. Instead of being placed in special schools and separate classrooms, children with hearing loss are now being taught in regular classes alongside children with normal hearing. In addition, the number of children with educationally significant hearing loss has steadily risen because of an increase in incidences of otitis media and minimal sensorineural hearing loss. There are, of course, acoustic barriers to listening and learning in the classroom for all children, but especially so for those with hearing loss. Many more children experience difficulty hearing and comprehending in noisy, active classrooms these days, resulting in significant but reversible educational delays. As this chapter will show, improvements in classroom acoustics should remove many of the current acoustic barriers, should enhance listening and learning for all children, and should prove to be a good investment for local school districts.

Introduction

The need for improved acoustics in the classroom is widespread across the United States. In fact, evidence suggests that at least some students in every class in every mainstream school need a more favorable acoustic environment, but acceptable acoustics exist in only a few of those classrooms. Why the widespread need? Simply stated, some children in every classroom have trouble hearing. Today, there are more children with hearing loss and they are more likely to have a slight or mild — not just profound — hearing loss. In the past 20 to 30 years, after many of today's classrooms were built, significant educational changes have occurred. Classrooms today are more likely to be active, multi-center places of learning complete with noisy and distracting heating, ventilating, and air-conditioning (HVAC) systems. This combination of effects means that improved classroom acoustics are more important than ever.

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Table I. Etiologies of Childhood Hearing Loss Reported from 1986 and 1996 Surveys (*1986 and 1996 Annual Surveys of Deaf and Hard-of-Hearing Children and Youth,* Gallaudet Research Institute, Gallaudet University)

Distributions of Etiologies, Students Who Are Deaf or Hard of Hearing				
Etiology	*1986*		*1996*	
	Count	*(%)*	*Count*	*(%)*
Maternal rubella	3885	(8%)	720	(2%)
Trauma at birth	1179	(2%)	1123	(2%)
Complications of pregnancy	1452	(3%)	1056	(2%)
Heredity	6042	(12%)	6123	(13%)
Prematurity	2140	(4%)	2177	(5%)
Cytomegalovirus	169	(0%)	748	(2%)
Rh incompatibility	452	(1%)	184	(0%)
Other cause (before birth)	2237	(5%)	2773	(6%)
Meningitis	4168	(9%)	3276	(7%)
High fever	1517	(3%)	982	(2%)
Mumps	53	(0%)	13	(0%)
Infection	1351	(3%)	1025	(2%)
Measles	233	(0%)	77	(0%)
Otitis media	1710	(4%)	1867	(4%)
Trauma after birth	350	(1%)	285	(1%)
Other cause (after birth)	1272	(3%)	1449	(3%)
Cause cannot be determined	11,306	(24%)	11,525	(26%)
Cause data not available	9654	(20%)	11,451	(25%)

Changing Etiology and Degree of Hearing Loss

The depiction of educating children with hearing loss has changed significantly in recent years. Some causes of hearing loss have decreased dramatically in incidence. Compared with previous decades, more children are identified with mild or moderate hearing loss and are being educated in mainstream classrooms. This change in etiologies is shown in the reports summarized in Table I.

As shown in Table I, several causes of profound hearing loss (e.g., rubella and meningitis) have been greatly reduced through successful childhood immunization programs. As Gold (1999, p. 515) wrote:

Bacterial meningitis caused by Haemophilus influenzae type B (HiB) *has almost disappeared from the United States, Canada, and other countries that have implemented routine vaccination with HiB conjugate vaccines. The overall incidence of meningitis in these countries has declined by more than 50%, and the age distribution of susceptibility has shifted, so that the disease is now more common in adults than in children.*

Thus, in recent years, rubella or meningitis (which are known to cause profound hearing loss) are no longer the primary etiologies for children with hearing loss. More families cite etiologies associated with variable hearing loss, such as cytomegalovirus (CMV). The severity pattern of childhood hearing loss, it seems, has changed. In its 1986 *Annual Survey of Deaf and Hard-of-Hearing Children and Youth,* Gallaudet University surveyed 48,720 students with hearing loss. Of these, 19,917 had profound hearing loss (40.9%) and 11,150 (22.9%) had moderate or mild hearing loss. In contrast, when Gallaudet surveyed nearly the same number of students in 1996 (48,274), 16,185 had profound hearing loss (33.5%) while 15,953 (33%) had moderate or mild hearing loss. The Gallaudet survey tracked a similar number of children with hearing loss in that 10-year period, yet clearly there was a significant shift in degree of hearing loss (see Table II).

Changes in Ethnic Background and Incidence of Hearing Loss

The racial/ethnic background of documented students with hearing loss has also changed somewhat in recent years. From 1977 to 1997, the proportion of Hispanic students noted in Gallaudet University's annual survey has increased from 9% of the total population to 18% (Holden-Pitt & Diaz, 1998). Although

Table II. Degree of Hearing Loss Reported from 1986 and 1996 Surveys (*1986 and 1996 Annual Surveys of Deaf and Hard-of-Hearing Children and Youth,* Gallaudet Research Institute, Gallaudet University)

Distributions of Levels of Hearing Loss, Students Who are Deaf or Hard of Hearing, 1986–1996

Degree of Hearing Loss	*1986*			*1996*		
	Count	*(%)*		*Count*	*(%)*	
Normal: <27 dB	3114	(7%)	25%	5262	(11%)	35%
Mild: 27–40 dB	3693	(8%)		5112	(11%)	
Moderate: 41–55 dB	4575	(10%)		5808	(13%)	
Moderate-to-Severe: 56–70 dB	6274	(13%)		5684	(12%)	
Severe: 71–90 dB	9410	(20%)	63%	7923	(17%)	52%
Profound: 91+ dB	20,115	(43%)		16,308	(35%)	

Table III. Incidence of Hearing Loss (per 1000 Children) Noted on Health Surveys*

Group	*Slight Hearing Loss*	*Moderate or Greater Loss*	*Total per 1000 with Hearing Loss*
African-American	9.4	7.6	18.0
Cuban-American	56.6	11.7	63.3
Mexican-American	21.8	5.8	27.6
Puerto Rican-American	48.1	9.6	57.7
White, non-Hispanic	11.8	3.7	15.5

*Lee, D.J., Gomez-Marin, O., & Lee, H.M. (1996). Prevalence of childhood hearing loss. The Hispanic Health and Nutrition Examination Survey and the National Health and Nutrition Examination Survey II. *American Journal of Epidemiology, 144*(5), 442-449.

these figures mirror similar increases in the Hispanic population of the United States in general, the incidence of hearing loss among some Hispanic subgroups seems to be significantly higher than for others (see Table III).

Note the high incidence of hearing loss (especially slight and mild loss) among some Hispanic subgroups. Schools with large concentrations of Cuban-American and Puerto Rican-American children can expect to have a very high incidence of children with slight hearing loss.

Changes in School Placements

Not surprisingly, the number of students in residential placements has decreased. Between 1986 and 1996, the percentage of children enrolled in residential schools declined from 24% to 19% of the total. Thus, in 1996, 65% of the children with hearing loss were enrolled in regular educational facilities, as shown in Table IV.

Increase in *Otitis Media*

The incidence of *otitis media* (OM) among children is also at an all-time high (Stool, Berg, Berman, Carney, Cooley, Culpepper, Eavey, Feagans, Finitzo, Friedman, 1994). OM is a temporary, recurring middle ear infection that is often accompanied by the presence of fluid in the middle ear (effusion). The incidence of OM doubled between 1975 and 1990 (Schappert, 1992). It is the most common medical diagnosis for children, accounting for 6 million office visits in 1990 for children between the ages of 5 and 15 years (Stool et al., 1994). Estimates show that there are 70 bouts of OM annually per 100 children under the age of 5 years. An additional 25% more are invisible and uncounted, and only half of the OM bouts clear within a month, whether treated or not. During that month (or longer), the child's hearing loss will

Table IV. School Placement Data from 1986 and 1996 Surveys (*1986 and 1996 Annual Surveys of Deaf and Hard-of-Hearing Children and Youth*, Gallaudet Research Institute, Gallaudet University)

Facility Type	*1986*		*1996*	
	Count	*(%)*	*Count*	*(%)*
Residential school	11,399	(25%)	8896	(20%)
Day school	4595	(10%)	3863	(9%)
Regular educational facility	25,480	(57%)	28,458	(65%)
Other	3354	(7%)	2475	(6%)

fluctuate, varying between 0 dB HL and 40 dB HL. One can easily do the math and figure that there may be 20 bouts of OM for 30 children in a first-grade class, with each bout averaging 3–4 weeks.

Increasing Reports of Minimal Hearing Loss

Two recent studies by Niskar, Kieszak, Holmes, Esteban, Ruben, and Brody (1998) and Bess, Dodd-Murphy, and Parker (1998) have uncovered surprising numbers of children with slight hearing loss. Niskar et al. (1998) performed a study for the Centers for Disease Control and Prevention on 6000 children ages 6 to 19 years. They found that a surprising 15% had hearing loss of at least 16 dB. Of these, 7% had low-frequency hearing loss and 13% had high-frequency loss; some children had both.

Bess, Dodd-Murphy, and Parker (1998) found similar results in a study of 1,200 children in Tennessee. Of this study population, 13% had slight hearing loss. When compared with a matched control group, a much greater retention rate was observed for children with slight hearing loss (37% of children with slight hearing loss repeated at least one grade, as opposed to only 3% of the control group). The children with slight hearing loss were usually unaware of their loss, yet they exhibited significantly greater dysfunction than children with normal hearing on several tests of behavior, energy, stress, social support, and self-esteem. Among the younger children, there were large communication differences between those with and without hearing loss. Third-grade children with slight hearing loss exhibited significantly lower scores than did controls on a series of communication subtests of a standardized academic achievement test.

Clearly, there are many children with hearing loss, with most of them having mild or slight hearing loss. It may be assumed, therefore, that many of them are not aware of their hearing loss and that they do not use hearing aids or assistive listening devices. Those children rely on good acoustic conditions and favorable signal-to-noise ratios (SNRs) in the classroom to be able to hear and comprehend the teacher and their peers.

The literature clearly suggests that hearing loss (even slight) is often accompanied by delayed acquisition of vocabulary, reduced incidental learning, frequent and significant academic delay, and, most often, limited reading abilities (Ross, 1990). However, there is recent evidence on the effects of early intervention (Yoshinaga-Itano, Sedey, Coulter, & Mehl, 1998) that demonstrates what we have always suspected: that none of these deficits is a necessary consequence of hearing loss. Rather, these deficits are consequences of reduced communication opportunities between the child with hearing loss and the rich spoken language environment. If we are able to overcome the barriers to communication, we can allow the child with hearing loss to learn normally. A large body of evidence (e.g., ASHA, 1995; Crandell, Smaldino, & Flexer, 1995) suggests that if we provide an acoustic environment that allows an SNR of at least +15 dB, then all participants will be able to hear well enough to fully comprehend any communication experience. According to ASHA's committee on classroom acoustics, classrooms that maintain ambient noise levels of 35 dB(A) or less will allow speakers' voices to reach all listeners at the desired +15 dB SNR. This should be the goal for all classrooms.

Learning in Noisy Classrooms

Classrooms today remain noisy and are more active than in recent decades. In a recent study, reverberation and background noise levels were recorded in 32 unoccupied elementary classrooms in eight different public school buildings in Central Ohio (Knecht, Whitelaw, & Nelson, 2000). Of the 32 classrooms assessed, only four had background noise levels below the ASHA-recommended limit of 35 dB(A) (ASHA, 1995). Overall, background noise levels for the 32 classrooms seemed to be, on average, 10 dB–15 dB higher than recommended. Three classrooms had unoccupied noise levels of 55 dB(A) or higher. These findings are consistent with the findings of Crandell and Smaldino (1994). Although it was found that the noisiest classrooms were those with noisy HVAC units running, most exceeded noise criterion recommendations even when the HVAC systems were turned off. Teachers or instructional personnel who wanted to be heard in those situations would have to elevate their voices to near-shouting levels to be heard by all of their students.

In addition, reverberation in classrooms with hard walls and high ceilings can "smear" speech signals so that they are more difficult to understand. Reverberation times (RT) of 0.4–0.6 seconds are considered excellent for speech understanding in any type of room. Longer RTs result in audible echoes and diminished understanding and also add to the overall "loudness" of a room. RT measurements for the 32 classrooms in the Knecht, Whitelaw, & Nelson (2000) study ranged from 0.2 to 1.27 seconds. Only 6 of the 32 unoccupied classrooms met ASHA's RT criterion of 0.4 seconds, with the other classrooms exceeding the recommended RT. Again, these findings are consistent with those of Crandell and Smaldino (1994).

Learning in Active Classrooms

Learning paradigms for classrooms today seem to be changing, as recommended by practicing educators and educational researchers. It is generally accepted that active participation by students in any instructional exercise is of paramount importance for meaningful learning to occur at any level. Engaging students in hands-on activities is considered imperative to help them develop an understanding of concepts (Roychoudhury, 1994). An energetic, inclusive classroom develops the various forms of intelligence (e.g., linguistic, musical, spatial) in students (Stoll & Fink, 1996). Wolf, Bixby, Glenn, & Gardner (1991) describe the active learning paradigm in the following way:

> *Learning at all levels involves sustained performances of thought and collaborative interactions of multiple minds and tools as much as individual possession of information (p. 49).*

Thus, active classrooms are noisier than the unoccupied classrooms described above. Many busy modern classrooms can be assumed to have noise levels of 70 dB(A) and higher if, as occasionally noted in Knecht et al. (2000), unoccupied background noise levels are greater than 55 dB(A). When ambient noise levels are high in empty classrooms, children naturally raise their voices to be heard during classroom activities. These conditions result in SNRs that are difficult for all children, and even more so for children with mild hearing loss. Children who require favorable learning conditions are often unable to participate among all the commotion.

The primary classrooms are particularly active and noisy as children move, participate, and share knowledge with one another. The younger children who are more likely to have hearing loss due to OM (Stool et al., 1994) are found in these grades. At this level, some of the most critical auditory-based instruction in reading occurs.

To complicate matters, amplification systems are of less help in active classrooms where there are high levels of participation. Many times throughout the day, children need to hear each other's voices, not the voice of the teacher. Personal hearing aids cannot provide improved SNR, and personal assistive devices — such as frequency modulation (FM) amplification systems — only improve reception of the microphone-wearer's voice. Improving acoustics in the classroom can help provide a favorable environment in which quiet activity and successful communication with all classroom members can occur.

Summary

Good classroom acoustics can benefit all children, but especially those children with hearing loss (no matter how slight) who are trying to participate in vibrant learning environments. These children and conditions are so prevalent in our schools, particularly in the critical early grades, that we can

assume every classroom merits attention to good acoustics. There is a clear relationship between a child's inability to hear and that child's reduced learning rate. The cost of a lack of attention to acoustics will undoubtedly exceed any costs of renovation or upgrades to new construction.

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4 Acoustical Modifications for the Classroom

Carl C. Crandell, Ph.D., and Joseph J. Smaldino, Ph.D.

It is well recognized that inappropriate levels of classroom reverberation and/or noise can deleteriously affect speech perception, reading and spelling ability, behavior, attention, concentration, and academic achievement. The first strategy for improving speech perception within a classroom should be acoustical modification of that environment. With these considerations in mind, this article will review procedures for evaluating, measuring, and modifying noise and reverberation levels in the classroom environment.

Introduction

To improve speech perception within the classroom, the first strategy adopted should be acoustical modification, or alteration, of that environment. Without appropriate modification of the room, even the most advanced hearing-assistive technology may not provide adequate speech understanding. As other articles in this monograph show, acoustical guidelines for children with hearing loss recommend that signal-to-noise ratios (SNRs) should surpass +15 dB, unoccupied noise levels should not exceed 30–35 dB(A), and reverberation times (RTs) should not be higher than 0.4 seconds. Unfortunately, these ideal acoustical conditions are rarely attained in most learning environments. For example, McCroskey and Devens (1975) found in a study of nine elementary school classrooms that the recommended acoustical conditions had been achieved in only one classroom, and Crandell and Smaldino (1995) reported that none of the 32 classrooms they studied met recommended criteria for noise levels.

One reason for the discrepancy between acoustical guidelines and actual room conditions is that classrooms often exhibit minimal degrees of acoustical modifications. Bess, Sinclair, and Riggs (1984) reported, for example, that while 100% of the rooms they studied had acoustical ceiling tile, only 68% had

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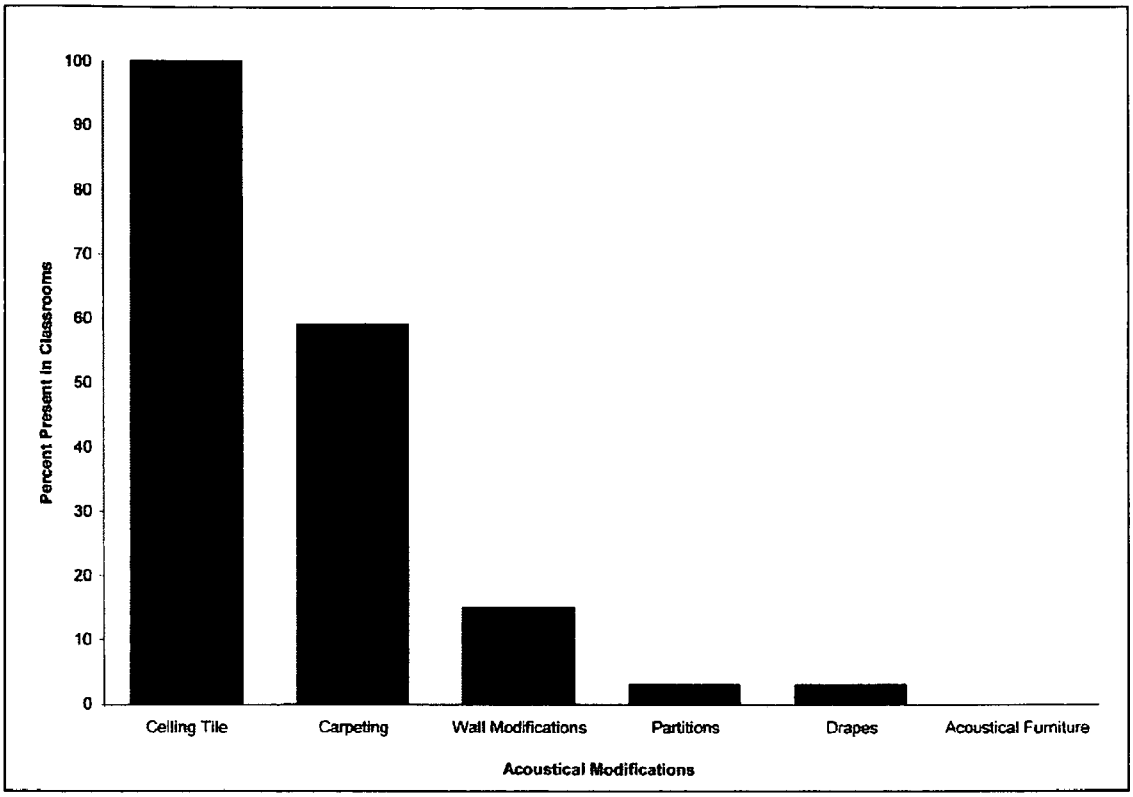

Figure 1. Acoustical treatments in classrooms. [Adapted from Crandell, C. & Smaldino, J. (1994). An update of classroom acoustics for children with hearing impairment. *The Volta Review, 96*(4), 291-306.]

carpeting and only 13% had draperies. Furthermore, none of the classrooms contained any form of acoustical furniture treatment. In the study by Crandell and Smaldino (1994), each of the 32 classrooms that were studied contained acoustic ceiling tile, but only 59% had carpeting. Only 15% of the rooms exhibited acoustical wall modifications, only 3% had partitions, and only 3% had drapes (see Figure 1). None of the rooms used acoustically modified furniture.

This chapter will review procedures for evaluating, measuring, and modifying the classroom environment. However, for detailed discussions on acoustical modifications and the reduction of noise and reverberation in the classroom, readers should consult the following resources: Barron (1993); Crandell, Smaldino, & Flexer (1995); Crandell, Siebein, & Smaldino (In Press); Crandell & Smaldino (2000, In Press); Egan (1987); Knudsen & Harris (1978); Harris (1991); and Siebein (1994).

Classroom Measurement

The classroom is a very complex and ever-changing acoustic environment. One of the most difficult aspects of measuring or controlling the acoustic environment in a classroom is that acoustic parameters change as a function

of time. For example, the SNR in the classroom changes constantly because of variations in the intensity of the teacher's voice and/or ambient noise in the classroom. Therefore, before an audiologist or other professional can consider changes in the acoustic environment, he or she must have an understanding of the status and dynamics of the particular classroom. The most straightforward way to gain this understanding is to observe the classroom carefully under real-life conditions (i.e., with the teacher and students in the classroom) during the school day. Because there are many teaching configurations during a school day, the configurations in which this instruction takes place must be considered separately. If that is not done, measurements obtained when students are seated and the teacher is speaking from the front of the room might not be descriptive of a situation when the students are in small groups and the teacher is moving around. Thus, the first step in making classroom acoustic measurements is to determine the placement of students and teacher when most instruction takes place. The distance between the teacher and the students should be documented, as should the distance between individual students. Moreover, the audiologist must be aware of teaching style, obvious sources of background noise, additional types of technology in the room, and what type of disabilities (such as hearing loss) the children may have.

Reverberation

Measurement of Reverberation

As discussed above, reverberation refers to the prolongation or persistence of sound within an enclosure subsequent to sound waves reflecting off hard surfaces (i.e., bare walls, ceilings, windows, floor). Reverberation time refers to the amount of time it takes for a sound at a specific frequency to decay 60 dB following termination of the signal. Reverberation is usually measured by presenting a high-intensity, broad-band stimulus (such as white or pink noise) into an unoccupied room and measuring the amount of time required for that signal to decay 60 dB at various frequencies (Nabelek & Nabelek, 1994; Siebein, Crandell, & Gold, 1997). Commercially available instruments for recording RT vary from inexpensive, compact battery-units that allow the audiologist to conduct simple measurements to highly technological, computer-based devices that can measure and record numerous aspects of an environment's decay properties. Reverberation time can also be estimated from various formulae.

Since the primary energy of speech exists between 500 Hz and 2000 Hz, RT is often reported as the mean decay time at 500, 1000, and 2000 Hz. Unfortunately, such a measurement might not adequately describe the reverberant characteristics of a room because high RTs may exist at additional frequencies. Room reverberation varies as a function of frequency and should therefore be measured at discrete frequencies. Generally, because most materials do not absorb low frequencies well, room reverberation is shorter at

higher frequencies and longer in lower frequency regions. It is recommended that whenever possible RT be measured at discrete frequencies, from 125 Hz to 8000 Hz. Such information could significantly aid the audiologist in determining the appropriate degree and type of absorptive materials needed to reduce RT in that environment.

It is often the case, however, that an approximation of the RT helps determine whether a more extensive measurement is worthwhile. The following section provides a simple paper-and-pencil procedure for estimating RT in a classroom (Crandell et al., 1995). This procedure requires 20 feet of measuring tape (or an ultrasonic distance estimator) and a calculator. Use the following formula to estimate classroom reverberation:

$$RT = [.05 \times V]/A \qquad (1)$$

where: RT = reverberation time in seconds
.05 = a constant
V = volume of the room
A = total absorption of the room surfaces in sabins.

Step 1: All of the reverberation estimates should be conducted in an unoccupied classroom. Because a formula is used, no improvement in accuracy is obtained with students and teacher present. During more detailed measurements, however, the presence of the room occupants might be desirable.

Step 2: Calculate the volume of the classroom. This is done by measuring the length, width, and height of the classroom in feet and multiplying these measurements together (i.e., volume = length of room × width of room × height of room).

Step 3: Multiply the volume of the room by the constant .05 to obtain the numerator for Equation (1) above.

Step 4: To obtain the denominator of the equation, the area of the room's walls, floor, and ceiling must first be calculated in square feet. If the walls, ceiling, or floor are irregularly shaped, each section must be measured separately. The area of the floor and ceiling is determined by multiplying the length of the floor or ceiling by its width. The area of the walls can be obtained by multiplying the length of each wall by its height.

Step 5: A useful index in determining the reverberant characteristics of a room is the absorption coefficient (α). The absorption coefficient refers to the ratio of unreflected energy to incident energy present in a room. In other words, the absorption coefficient is a measure of the sound reflectiveness of different construction materials. The coefficient, expressed in sabins, must be determined for the material composing the walls, ceiling, and floor. Average absorption coefficients are given in Table I for the most common construction materials.

Step 6: Multiply the area of each floor, ceiling, and wall by the absorptive coefficient of the material composing the surface. Add up the results to obtain what is known as A (i.e., total absorption of the room in sabins).

Table I. Average Sound Absorption Coefficients for Ceiling, Floor, and Wall Materials Commonly Found in Classroom Construction*

Ceilings	*Absorption Coefficient*
Plaster, gypsum, lime on lathe	0.05
Suspended $^5/_8$-inch acoustical tiles	0.68
Suspended $^1/_2$-inch acoustical tiles	0.66
Not suspended $^1/_2$-inch acoustical tiles	0.67
Suspended high-absorptive panels	0.91
Floors	*Absorption Coefficient*
Wood parquet on concrete	0.06
Linoleum	0.03
Carpet on concrete	0.37
Carpet on foam padding	0.63
Walls	*Absorption Coefficient*
Brick	0.04
Painted concrete	0.07
Window glass	0.12
Plaster on concrete	0.12
Plywood	0.32
Concrete block	0.33

*Adapted from Berg, F. (1993). *Acoustics and sound systems in schools.* San Diego, CA: Singular Press.

Step 7: Take the numerator from Step 3 ($.05 \times V$) and the denominator from Step 6 (A = total absorption in sabins for the room) and divide them to determine the room's estimated RT in seconds ($RT = .05 \times V/A$). If the RT is higher than 0.4 seconds, or if excessive high- or low-frequency reverberation is suspected, a more complete evaluation of reverberation should be conducted.

Reduction of Room Reverberation

The degree of absorptive surfaces within a room will affect the reverberant characteristics of that environment. Materials with hard, smooth surfaces such as concrete, cinder block, and hard plaster are poor absorbers, while materials that have soft, rough, and/or porous surfaces (e.g., cloth, fiberglass, or corkboard) tend to be good sound absorbers. Classrooms with bare cement walls, floors, and/or ceilings tend to exhibit higher RTs than rooms that contain

absorptive surfaces such as carpeting, draperies, and acoustical ceiling tile. As noted above, a useful index in determining the reverberant characteristics of a room is the absorption coefficient. A surface with an absorption coefficient of 1.00 would technically absorb 100% of all reflections, while a surface structure with an absorption coefficient of 0.00 would reflect all of the incident sound. Absorption coefficients, which are typically indicated from 125 Hz to 4000 Hz, are frequency dependent. Specifically, most surface materials in a room do not absorb low-frequency sounds as effectively as they absorb higher frequencies. Because of these absorption characteristics, room reverberation is often shorter at higher frequencies than in lower frequency regions. Generally, surfaces are not considered absorptive until they reach an absorption coefficient of 0.20. Unfortunately, there is a tendency to treat most or all of the surfaces in a room with sound-absorbing materials. If all of the surfaces become sound absorbent, however, then the teacher is effectively speaking in an anechoic or nonreverberant environment. Thus, the teacher would have to raise his or her voice or use an amplification system to overcome the lack of reflected sounds that would normally be present in a room.

Simply stated, reverberation can be reduced by covering the hard, reflective surfaces in a classroom with absorptive materials such as acoustical paneling. Ceilings, for example, should be covered with acoustical paneling. Acoustical tile can be suspended from the structural deck and should have an absorption coefficient of at least 0.65. Acoustical panels may also be placed on walls, but typically not on walls parallel to one another. Cork bulletin boards, carpeting, and bookcases can also be strategically placed on the walls; however, these materials are not as absorptive as acoustical paneling. Interestingly, the installation of most of these absorptive materials will not only reduce reverberation in the environment, but will also decrease the noise level in the room.

Thick carpeting on the floors can also significantly reduce reverberation (and noise) in a room. In fact, rooms that contain both ceiling tile and carpets have approximately 60% of surfaces within that room covered with absorptive material. However, rooms with just the ceiling and floor covered may be prone to acoustical defects such as flutter echoes. Flutter echoes are the continued reflection of sound waves between two opposite parallel surfaces, which can be heard as a distinctive "slapping" sound. Absorbent materials can be placed on the walls and splayed slightly to reduce this problem. Sound-absorbent acoustical panels can also be placed on the sidewalls at the front of the room to reduce flutter in the area where the teacher mostly speaks.

To reduce reverberation, curtains or thick draperies can be placed over the windows' hard reflective surfaces. Even when the curtains are open, they will serve to minimally reduce RT in the enclosure. In addition, positioning of mobile bulletin boards and blackboards at angles other than parallel to opposite walls will reduce the reflected sound within an enclosure. Some teachers have also used creative artwork — from egg cartons or carpet scraps attached

The Sound Network

The A-weighting network is designed to simulate the sensitivity of the average human ear under conditions of moderate sound loudness (40 phons). The B-weighting network simulates loud sound (70 phons) and the C-weighting network approximates how the ear would respond to a very loud sound (100 phons). The convention for measuring room and factory noise is to use the A-weighting network.

to walls or suspended from ceilings — to help absorb noise and reduce reverberation. Keep in mind, however, that safety regulations must be checked before potentially non-fire-retardant materials may be placed in the classroom.

Background Noise

Measurement of Background Noise

Background noise refers to any auditory disturbance within the room that interferes with what a listener wants to hear (Crandell, Smaldino, & Flexer, 1995). Other articles in this monograph discuss how background room noise can originate from external and/or internal sources. Background noise can also originate from within the room itself. In order to conduct the most appropriate modification of the room, it must first be determined which noise source (or sources) needs to be reduced. Background noise in a classroom is often measured in an unoccupied setting, since it is difficult to accurately characterize noise in an occupied room because of changing activities that tend to take place in that room. To simplify the measurement process, single-number descriptors are often used to describe the background noise. One such designator of room noise is measurement of the relative sound pressure level (SPL) of the noise at a specific point or points in time on an A-weighted scale — a measurement usually conducted with an instrument called a sound level meter. Sound level meters range from compact, inexpensive, battery-operated units to computer-based devices that can measure and record numerous properties of a signal. They are classified according to standards set forth in ANSI S1.14–1983, *American National Standard Specification for Sound Level Meters* (ANSI, 1983). Type I sound level meters meet the most rigorous standards, while Type II and Type III meters are for general purpose and hobby use, respectively. The most serious measurement of room noise would require at least a Type II meter, but preferably a Type I unit. Many sound level meters incorporate weighting filter networks (i.e., A, B, and C).

It should be noted that any number obtained from a sound pressure measurement performed with A-weighting can be obtained with several very different spectra. Sometimes, an analysis of the spectra producing the noise can

better indicate the interference that the spectra may impose on a speech signal. A more thorough approach to measuring noise in an enclosure is to conduct a spectral analysis of the noise (usually 63 Hz–8000 Hz), which requires an octave-band filter network associated with the sound level meter.

Another procedure for evaluating the effects of noise on speech communication is to use of Noise Criteria (NC) curves (Beranek, 1954). NC curves are a family of frequency/intensity curves based on octave-band sound pressure across a 20 Hz–10,000 Hz band and have been related to the successful use of an acoustic space for a variety of activities (see Figure 2). When using NC curves, sound levels are plotted across eight standard frequencies. The NC value that characterizes a room is determined by the highest octave-band SPL that intersects the NC family of curves. Thus, in Figure 3, the NC curve would be 50 dB. The NC rating is generally 8 dB–10 dB below the dB(A) level of that room.

It is recommended, whenever possible, that background noise levels in rooms be measured via NC measures, since this procedure gives the examiner additional information on the spectral characteristics of the noise. With this information, the audiologist or acoustical engineer can isolate and modify sources of excessive noise in the room. Appropriate NC units for various rooms are shown in Table II. The effects of different NC units on communicative efficiency are presented in Table III.

Room Criteria (RC) curves are similar in concept to NC curves. In the development of RC curves, NC curves were modified at very low and very high frequencies to include frequencies commonly associated with mechanical noises, such as heating or air-conditioning units.

Often, an approximation of the classroom background noise and SNR is needed to determine whether it is worthwhile to conduct more extensive measurements. The following is a simple procedure for estimating these variables in a classroom (Crandell et al., 1995), requiring the following: (1) a sound level meter (must have A-scale and slow response); (2) a 20-foot measuring tape; and (3) a standard reading passage from a book or other instructional material.

Step 1: Position the teacher in the normal instructional position in the classroom. The students should be seated in their normal seats for instruction. It is important that the measurements are made in the period when instruction normally occurs, so that the acoustic conditions are representative of actual instructional environments.

Step 2: Turn on the sound level meter; be sure it is set on the A-scale and on slow response. If you can set the range of the meter, set it to accommodate 40 dB–60 dB SPL to begin.

Step 3: Position the sound level meter to approximate the center of each selected student's head while he or she is seated at his or her desk. Point the sound level meter toward the teacher's position, taking care to avoid placing your body in the sound path between the teacher and the student, which can produce inaccurate measurements. Student desks at the four corners, the middle, and the middle back of the classroom seating should be measured. More locations can be measured if desired.

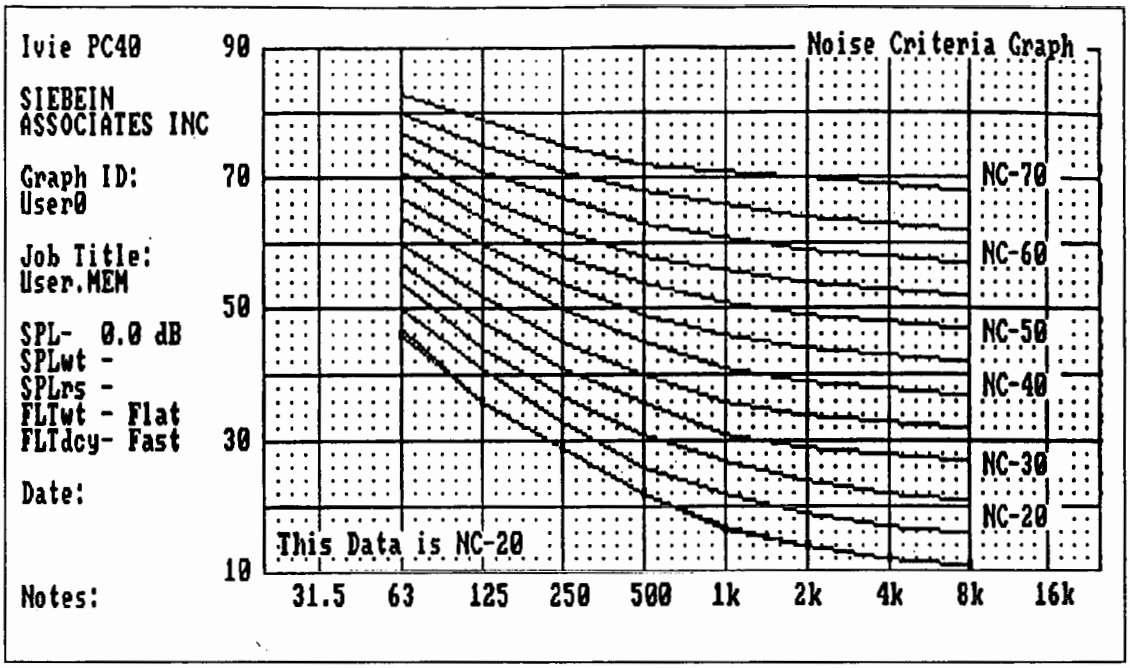

Figure 2. Noise Criteria Curves. [Figure from Berg, F. (1993). *Acoustics and sound systems in schools.* San Diego, CA: Singular Press. Used with Permission.]

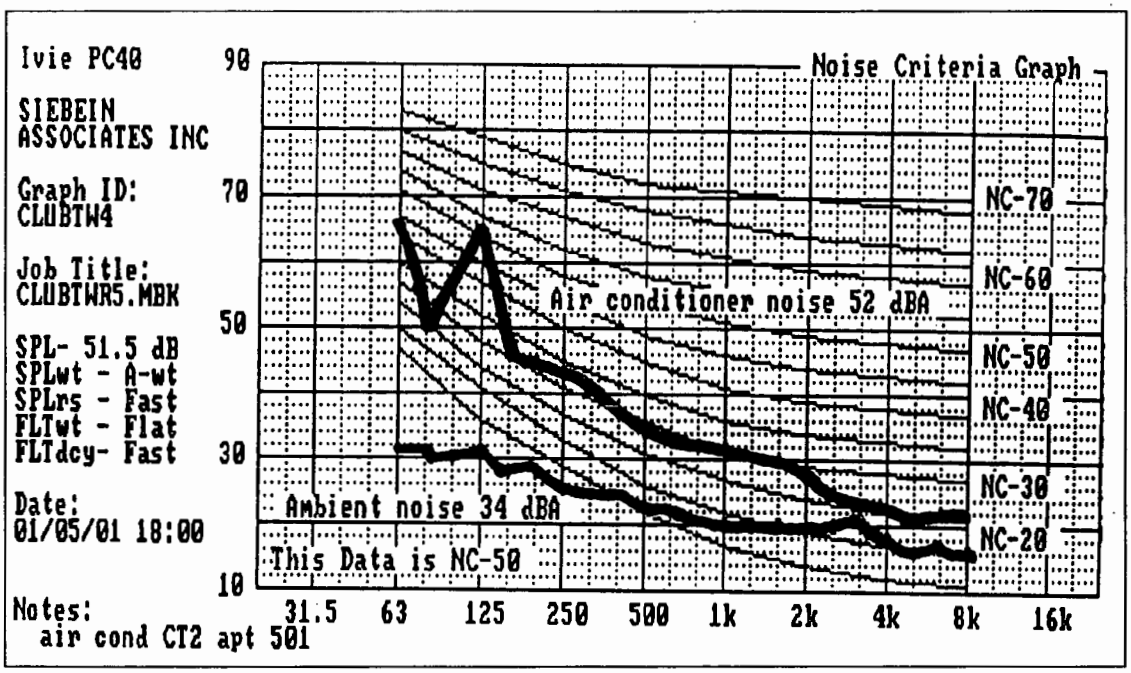

Figure 3. Noise Criteria Curves for an NC of 50. [Figure from Berg, F. (1993). *Acoustics and sound systems in schools.* San Diego, CA: Singular Press. Used with Permission.]

Table II. Acceptable Noise Criteria (NC) Curves and Related A-Weighted Sound Pressure Levels in dB(A) for Various Listening Environments*

Listening Space	*NC Curves*	*Equivalent dB(A) Levels*
Broadcast studios	15–20	25–30
Concert halls	15–20	25–30
Classrooms (no amplification)	25	35
Apartments and hotels	25–30	30–35
Homes (sleeping areas)	25–35	35–45
Libraries	30	40–45
Restaurants	45	55

*Adapted from Berg, F. (1993). *Acoustics and sound systems in schools.* San Diego, CA: Singular Press.

Table III. Relationship of Noise Criteria (NC) Values to Communication Efficiency*

NC Curves	*Equivalent dB(A) Levels*
20–30	Very quiet office, telephone use satisfactory, suitable for large conferences.
30–35	Quiet office, satisfactory for conferences at 15-foot table, normal voice at 10–30 feet, telephone use satisfactory.
35–40	Satisfactory for conferences at 6–8-foot table, telephone use satisfactory, normal voice 6–12 feet.
40–50	Satisfactory for conferences at 4–5-foot table, telephone use may be difficult, normal voice 3–6 feet, raised voice to 12 feet.
50–55	Unsatisfactory for conferences of more than 2–3 people, telephone use can be difficult, normal voice 1–2 feet, raised voice 3–6 feet.
More than 55	Very noisy, office environment is unsatisfactory, telephone use is difficult.

*Adapted from Berg, F. (1993). *Acoustics and sound systems in schools.* San Diego, CA: Singular Press.

Step 4: While the students are quiet, measure the ambient noise level at the selected student locations and record it on the classroom documentation form. If the noise level fluctuates, take three measurements at one-minute intervals, average the readings, and record those on the form. These measurements will provide an estimate of the ambient noise level during an instructional period. If measurements can be taken only when the students are not in the classroom (i.e., when it is unoccupied), you may convert the unoccupied noise levels to occupied levels by adding 10 dB to each unoccu-

pied measurement. This conversion is roughly equal to the known difference in noise level between average unoccupied and occupied classrooms.

Step 5: The teacher should begin reading the standard reading passage at a normal instructional intensity level.

Step 6: Repeat Step 4 now that the teacher is reading the standard passage.

Step 7: Subtract the ambient noise measurement from the teacher voice measurement to determine the SNR of the classroom at the selected student sites. For example, a student location with a teacher voice level of 60 dB(A) and a noise level of 50 dB(A) would have a SNR ratio of +10 dB. One with a teacher level of 60 dB(A) and a noise level of 70 dB(A) would have a SNR of -10 dB.

Reduction of Classroom Noise Levels

This section will examine procedures to reduce external noise sources (noise that is generated from outside the building), internal noise sources (noise that originates from within the building but outside the room), and classroom noise sources (noise that is generated within the room).

To reduce external noise levels, it is essential that rooms used for those with hearing loss be located away from high noise sources such as busy automobile traffic, railroads, construction sites, airports, and heating/air-conditioning units. The most effective way to achieve this goal is through appropriate planning with contractors, school officials, architects, architectural engineers, audiologists, and teachers for those who are deaf or hard of hearing before the school building is designed and constructed. Such consultation should include strategies for locating rooms away from high external noise sources. Moreover, acoustical modifications such as placement of vibration-reduction pads underneath the building's supporting beams to reduce structural-borne sounds can be implemented. Unfortunately, acoustic planning prior to construction is rare (Crandell & Smaldino, 1994; Crandell et al., 1995).

To further reduce external noise, the external walls of a classroom need to have a high sound transmission loss (STL) level — the amount of noise that is attenuated as it passes through a material. If an external noise of 100 dB SPL were reduced to 60 dB SPL in the room, the exterior wall of that room would have an STL of 40 dB SPL. A 7-inch concrete wall provides approximately 53 dB attenuation of outside noise, while windows and doors provide only 24 dB and 20 dB attenuation, respectively. Therefore, doors and/or windows on the external wall should be avoided in situations of high external noise levels. The STL of an external wall can be increased by (1) placing absorptive materials (such as fiberglass material) between the wall studs; (2) providing for thick or double concrete construction on the exterior wall; or (3) adding several layers of gypsum board (at least $^5/_8$ inches) or plywood material. All exterior walls must be free of cracks or openings, because even small openings in external walls can significantly reduce the STL. If windows are located on the external wall, they must be properly installed, heavily weighted or double-paned (such as storm windows), and should remain closed (whenever possi-

ble) if high external noise sources exist. Existing windows can be sealed with nonhardening caulk to increase the STL. Of course, check all safety regulations before sealing outside windows.

Creative landscaping strategies can also attenuate external noise sources. These strategies include the placement of trees or shrubs (particularly those that bloom all year) and earthen banks around the school building. Solid concrete barriers with an STL of 30 dB–35 dB can also be placed between the school building and the noise source to reduce external noise entering into the room.

Internal noise levels in the room can be reduced by relocating children in that room to a quieter area of the building. Rooms used by children with hearing loss should not be located next to a high noise source such as the gymnasium, metal shop, cafeteria, or band room. At least one quiet environment, such as a storage area or closet, should separate rooms from each other or from high noise sources in the building. If suspended ceilings separate the room from another room, then sound-absorbing materials should be placed in the plenum space above the wall. Double or thick wall construction should be used for the interior walls, particularly those walls that face noisy hallways or rooms. Additional layers of gypsum board, plywood, and/or the placement of absorptive materials between wall studding can also increase the attenuation characteristics of interior wall surfaces. All cracks between rooms should be sealed.

Acoustical ceiling tile and/or carpeting can be used in hallways outside the room to reduce internal noise. Certainly, all rooms should contain acoustically treated or well-fitting doors, preferably with rubber or gasket seals. Hollow-core doors between rooms and facing the hallway should not be used. Doors and interior walls should not contain ventilation ducts that lead into the hallways. Heating or cooling ducts that serve more than one room can be lined with acoustical materials or furnished with baffles to decrease noise being emitted from one room to another. Also, permanently mounted blackboards can be backed with absorptive materials to reduce sound transmission from adjacent rooms.

The simplest procedure to reduce the effects of classroom noise is to position children away from high noise sources, such as fans, air conditioners, heating ducts, and faulty lighting fixtures. Unfortunately, room noise sources are often so intense that no location in the room is appropriate for communication. In these cases, there must be acoustical modification of the room. Malfunctioning air-conduction/heating units and ducts should be replaced or acoustically treated. Heating ducts, for example, can be lined with acoustical materials — or fit with silencers — to reduce both vibratory and airborne noise. In addition, rubber supports and flexible sleeves or joints should be used to reduce the transmission of structural-borne noise through the ductwork system, and all fans and electrical motors in air-conditioning/heating units must be lubricated and maintained regularly.

Classroom noise can also be reduced by installing thick, wall-to-wall carpeting — with adequate padding — to dampen the noise of the shuffling of hard-soled shoes and the movement of desks and chairs. Acoustical paneling can

also be placed on the walls and ceiling. Acoustical paneling typically should be placed partly down the wall and not on walls parallel to one another. The placement of some form of rubber tips on the legs of desks and chairs can decrease room noise. This recommendation is particularly important if the room is not carpeted. Acoustically treated furniture can be purchased for rooms, though it must be noted that such furniture can be expensive and may present hygiene problems. Hanging thick curtains or acoustically treated venetian blinds over window areas to dampen room noise levels can be effective.

Certainly, open-plan rooms for children should be avoided; it is well recognized that such rooms are considerably noisier than regular rooms. Moreover, instruction should not take place in areas separated from other teaching areas by sliding doors, thin partitions, and/or temporary walls. Walls between instruction areas must be of sufficient thickness and continuous between the solid ceiling and floor. Walls that are not continuous allow for significant sound transmission between rooms. Fluorescent lighting systems, including the ballast, need to be regularly maintained and replaced. Typewriter or computer keyboard noise can be lowered by placing rubber pads or carpent remnants under such instruments. Whenever possible, such instruments (as well as any other office equipment) should be located in separate rooms. Rubber pads to reduce vibratory noise should be placed under all office equipment in the school.

Summary

Audiologists and teachers of the deaf or hard of hearing play a significant role in ensuring that acoustic barriers to communication are minimized. With that consideration in mind, this chapter reviewed known acoustic barriers to listening and learning in classrooms. Specifically, background noise, signal-to-noise ratio (SNR), and reverberation time (RT) were discussed. Based on considerable research, it was concluded that a prudent acoustical standard for listening and learning in many rooms for listeners with hearing loss would be an unoccupied noise level of no more than 30–35 dB(A) (or an NC curve of 20–25), a SNR of +15 dB or better, and a RT of 0.4 seconds. Simple procedures were suggested to improve room acoustics for children with hearing loss.

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5 Improving Classroom Acoustics: Utilizing Hearing-Assistive Technology and Communication Strategies in the Educational Setting

Carl C. Crandell, Ph.D., and Joseph J. Smaldino, Ph.D.

The acoustical characteristics of a classroom are important variables that can affect the academic achievement of all children. This chapter will examine acoustical, technological, and rehabilitative solutions for improving classroom acoustics and speech perception in the classroom setting. These procedures include: (1) physical acoustical modifications of the room; (2) personal hearing aids; (3) hearing-assistive technologies; (4) modifications in speaker-listener distance; (5) optimizing visual communication; (6) "clear" speech procedures; and (7) strategies for improving listening.

Introduction

It has been emphasized throughout this monograph that the acoustical environment of a classroom is an important variable in the psychoeducational and psychosocial development of both children with hearing loss and children with normal hearing. The existing literature suggests that inappropriate levels of classroom reverberation and/or noise can deleteriously affect speech perception, reading/spelling ability, classroom behavior, attention, concentration, and academic achievement (Berg, 1993; Bess & Tharpe, 1986; Blair, Peterson, Veihweg, 1985; Crandell, 1991; 1993; Crandell & Bess, 1986; Crandell & Smaldino, 1992, 1994a; Crandell, Smaldino, & Flexer, 1995; Finitzo-Hieber, 1988; Finitzo-Hieber & Tillman, 1978; Flexer, 1992; Olsen, 1988; Ross, 1978; Ross & Giolas, 1971). Certainly, the speech-perception difficulties experienced by children in the classroom highlight the need to provide an appropriate listening

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environment for all students. With these considerations in mind, this chapter will examine acoustical, technological, and rehabilitative solutions for improving speech perception in the classroom. These procedures include: (1) modifying physical acoustics of the room; (2) utilizing personal hearing aids; (3) implementing hearing-assistive technologies; (4) modifying speaker-listener distance; (5) optimizing visual communication; (6) adopting "clear" speech procedures; and (7) strategies for improving listening.

Acoustical Modifications for the Classroom

The topic of acoustical modifications for the classroom was discussed in detail in the Chapter 4. It was noted that acoustical modifications need to be the first area assessed and modified in order to improve speech perception in the classroom. For example, placement of carpeting on the floor and/or acoustic paneling on the ceiling and walls can significantly reduce noise and reverberation levels in many learning spaces. Of course, it is well recognized that the most effective procedure for achieving an acoustically appropriate classroom is through planning with contractors, school officials, architects, architectural engineers, audiologists, and teachers of children with hearing loss prior to the design and/or construction of the school building. Unfortunately, as pointed out in Crandell and Smaldino (1994b), acoustic planning prior to building construction is rare, but specific recommendations are available. For more detailed discussions on the proper placements of acoustical materials in the classroom, the reader is directed to Knudsen and Harris (1978), Egan (1987), Harris (1991), Barron (1993), Crandell et al. (1995), and Crandell and Smaldino (2000, In Press).

Unfortunately, appropriate acoustical conditions for children with hearing loss are infrequently achieved via acoustical modification of the classroom alone. As shown in other chapters in this monograph, acoustical guidelines for children with normal hearing or children with sensorineural hearing loss (SNHL) suggest that for optimal communication signal-to-noise ratios (SNRs) should exceed +15 dB, unoccupied noise levels should not exceed 30–35 dB(A), and reverberation times (RTs) should not surpass 0.4 seconds (through the speech frequency range). Research indicates that these acoustical recommendations are rarely achieved in most learning environments. Specifically, as shown in Tables I and II, the RT range for classrooms is typically 0.4–1.2 seconds, while classroom SNRs range from +5 dB to –7 dB (Blair, 1977; Crandell, 1992, 1993; Crandell & Smaldino, 1994b; Crandell et al., 1995; Finitzo-Hieber, 1988; Finitzo-Hieber & Tillman, 1978; Kodaras, 1960; Markides, 1986; McCroskey & Devens, 1975; Pearsons, Bennett, & Fidell, 1977; Ross, 1978).

Crandell and Smaldino (1994b) reported that only 7 of 32 classrooms (22%) used for children with hearing loss met recommended RT criteria. None of the classrooms studied achieved recommended criteria for background noise levels. McCroskey and Devens (1975) demonstrated that only 1 of 9 elementary classrooms met acoustical standards for background noise levels, while

Table I. Summary of Studies Examining Reverberation Times (RTs) in the Classroom

	Reverberation Time in Seconds
Kodaras (1960)	0.40–1.10
Nabelek and Pickett (1974)	0.50–1.00
McCroskey and Devens (1975)	0.60–1.00
Bradley (1986)	0.39–1.20
Crandell and Smaldino (1994a)	0.35–1.20

Table II. Summary of Studies Examining Signal-to-Noise Ratios (SNRs) in the Classroom

	Signal-to-Noise Ratio
Sanders (1965)	+1–+5
Paul (1967)	+3
Blair (1977)	-7–0
Markides (1986)	+3
Finitzo-Hieber (1988)	+1–+4

Crum and Matkin (1976) reported that only 1 of 11 classrooms met acoustical standards for noise.

One possible explanation for excessive levels of noise and reverberation in classrooms is that generally these spaces do not receive adequate acoustical treatments when being designed or constructed (Bess, Sinclair, & Riggs, 1984; Crandell, 1992; Crandell & Smaldino, 1994b). Crandell and Smaldino (1994b) reported that while each of 32 classrooms surveyed used acoustic ceiling tile, only 59% of the classrooms had carpeting. Few of the rooms contained acoustical wall modifications (only 15%), partitions (3%), or drapes (3%). None of the rooms had acoustically modified furniture. Regrettably, proper acoustical modification of classrooms is often overlooked or is deemed prohibitively costly for schools even to consider (Crandell et al., 1995).

Personal Hearing Aids

The communicative, perceptual, and psychosocial benefits of hearing aid use for the individual with hearing loss are well documented (see Crandell, 1998, for a review). Unfortunately, to date, many types of hearing aid styles and/or technologies offer minimal benefit in noisy or reverberant environ-

ments such as classrooms (Boothroyd, 1991; Crandell, 1991; Crandell et al., 1995; Duquesnoy & Plomp, 1983; Festen & Plomp, 1983; Finitzo-Hieber & Tillman, 1978; Plomp, 1978; Plomp, 1986; Van Tassell, 1993). This lack of benefit is not surprising, given that many forms of hearing aid signal processing do little to improve the SNR in a listening environment. Plomp (1986) reported that hearing aids offered limited speech perception when background noise levels exceeded 50 dB(A). In a similar investigation, Duquesnoy and Plomp (1983) reported that only minimum benefit was obtained from personal amplification when background noise levels reached 60 dB(A). Classrooms often exhibit background noise levels in excess of 50–60 dB(A).

Clearly, these data suggest that most children require more than a hearing aid in the classroom. It should be noted that several SNR-enhancing options are either currently available or under development for hearing aids, which may provide greater benefit in noisy environments. These technologies include directional microphones, digital processing, and beam-forming arrays. To date, however, there is limited empirical data concerning the usefulness of such technologies in the classroom setting.

Hearing-Assistive Technologies

Because hearing aids alone may not offer the child with SNHL adequate perceptual benefit, hearing-assistive technologies must often be used to augment speech perception in the classroom. A number of studies have demonstrated that when hearing-assistive technologies are correctly placed within classrooms, speech perception, psychoeducational, psychosocial, and academic improvements occur for both listeners with hearing loss and those with normal hearing (Berg, 1993, Crandell et al., 1995, Crandell & Smaldino, In Press). Possible classroom hearing-assistive technologies, as shown in Table III, include: (1) personal frequency modulation (FM); (2) sound-field FM; (3) induction loop; (4) infrared; and (5) hard-wired systems. For more complete descriptions of these systems, the reader should consult Compton (1993), Crandell and Smaldino (In Press), and Lewis (1998).

Table III. Hearing-Assistive Devices

- Personal Frequency Modulation (FM)
- Sound-Field FM Amplification System
- Induction Loop
- Infrared
- Hard-Wired

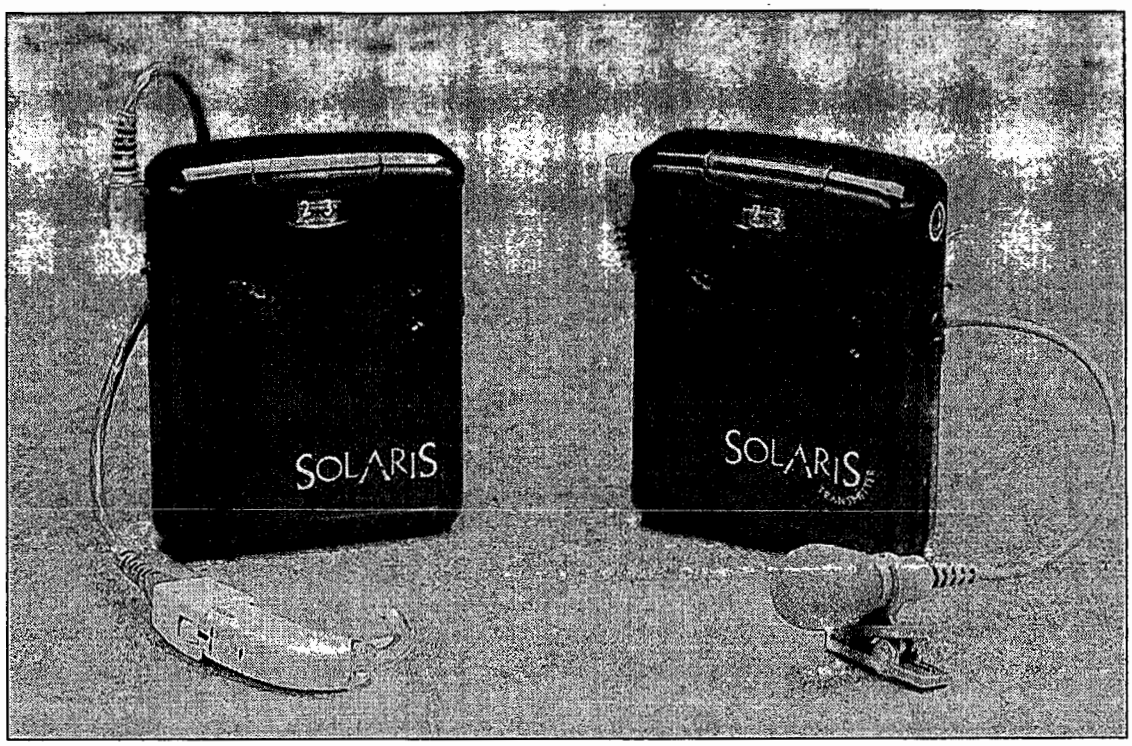

Figure 1. An example of a personal frequency modulation (FM) system. In this figure, the FM system is fitted to a hearing aid via direct audio input (DAI) technology. [Photo courtesy Phonic Ear, Inc.]

Personal Frequency Modulation (FM) Amplification

The most common forms of hearing-assistive technology used in the classroom today are personal FM systems. With a personal FM amplification system, or auditory trainer, the teacher's voice is picked up via an FM wireless microphone located 3–4 inches from the speaker's mouth (where the detrimental effects of reverberation and noise are minimal). The acoustic signal is then converted to an electrical waveform and transmitted via an FM signal to a receiver (see Figure 1). The electrical signal is then amplified, converted back to an acoustical waveform, and conveyed to one or more listeners in the room.

Children can receive the signal through headphones, ear buds, or directly through their hearing aids via induction loop or direct auditory input (DAI) technology. For individuals with conductive or mixed hearing loss, the FM system can be coupled to a bone conduction transducer. Because of the high SNR obtained by this form of technology (often 15–30 dB), FM systems are often a critical recommendation for students with even slight degrees of hearing loss who experience trouble extracting a signal from noise. Personal FM systems have recently become available for both children with SNHL and children with normal hearing in behind-the-ear models. Such models have been particularly useful for students in junior or senior high school who may not want to use larger personal FM systems because of the potential stigma traditionally associated with such

Table IV. Advantages and Disadvantages of Personal FM Systems

Advantages

- High degree of portability.
- Simple installation.
- FM systems can be used in many communication situations (large rooms/ small rooms, indoors/outdoors, field trips, broadcast media) that may not be practical for other forms of room amplification.
- High degree of electroacoustic flexibility.
- Buildings can have many rooms using FM systems as long as the transmission channels are selected to not interfere with one another.
- High mobility for speaker and listener.
- Not susceptible to electromagnetic interference.

Disadvantages

- User often has to wear a body-worn receiver.
- May be susceptible to FM interference from other sources
- Relatively high unit cost.
- Learning curve for use and maintenance.

devices. In addition, some FM systems permit a personal FM receiver to be added to a child's regular hearing aid. For a discussion of the advantages and disadvantages of various coupling strategies, the reader should consult Crandell and Smaldino (In Press) and Lewis (1998). Advantages and disadvantages of personal FM systems are shown in Table IV.

Sound-Field FM Amplification

A sound-field FM system is similar to a personal FM system. With sound-field FM amplification, however, the teacher's voice is delivered to children in the room via one or more strategically placed loudspeakers (see Figure 2). Sound-field FM systems are generally used to assist children with normal hearing since they will not improve the SNR as much as a personal FM system. The objective when placing a sound-field FM system in a classroom is to uniformly amplify the teacher's voice by approximately 8–10 dB. Sound-field systems can be used for children with SNHL if personal FM systems have been unsuccessfully attempted. However, efficacy must be measured to ensure benefit to the child.

Sound-field systems vary from compact, portable, battery-powered, single-speaker units to more permanently placed, AC-powered speaker sys-

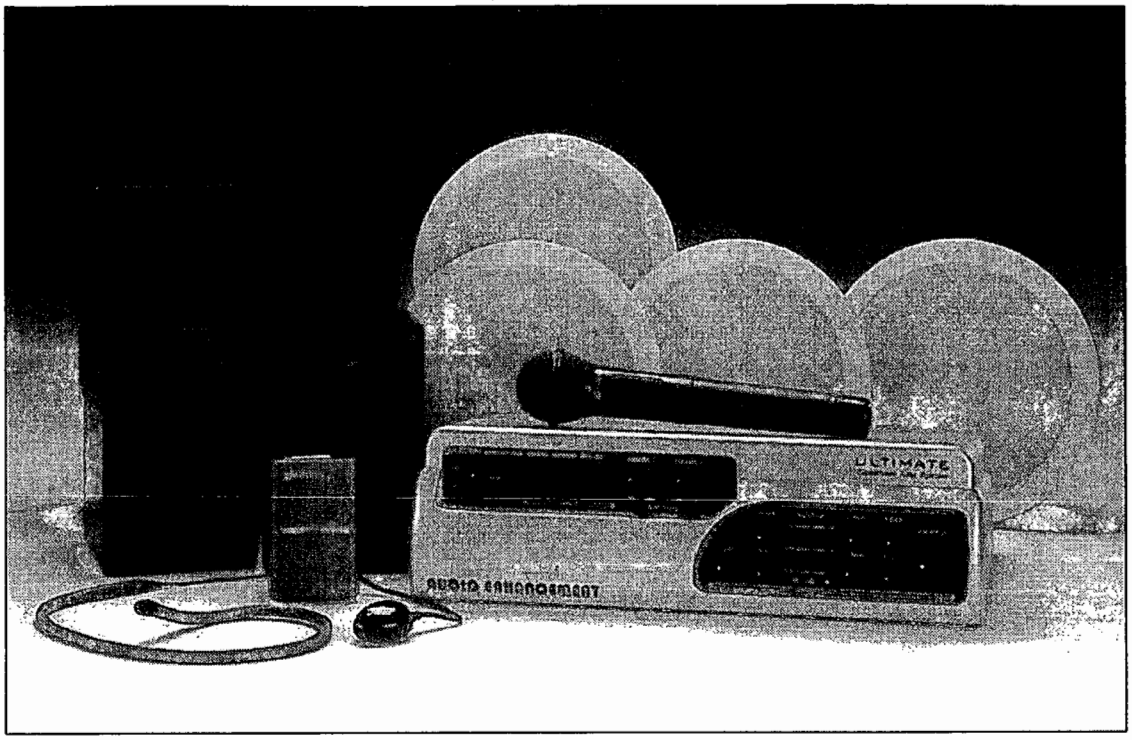

Figure 2. Components of a sound-field frequency modulation (FM) system. Note that in this photo there are floor and ceiling loudspeaker arrangements. [Photo courtesy Audio Enhancement.]

tems that use multiple (usually four) loudspeakers. Loudspeakers are generally placed on stands and strategically placed within the classroom. Several companies now market loudspeakers that can be placed in the ceiling. Advantages and disadvantages of sound-field FM systems are shown in Table V.

It should be noted that the placement of sound-field amplification systems in the classroom have been shown to be extremely cost-effective. To illustrate, if it is estimated that the average cost of a sound-field system is $700, and the cost is divided by all of the children in the classroom (since it will benefit all of the children), this equates to approximately $28 per child (considering a class size of 25 students). If this cost-per-student is computed over a 10-year period (the estimated lifespan of a sound-field system) the unit cost per child is only $2.80. This per-student cost can be further reduced if a decrease in need for special services for specific students is factored in.

Infrared Light-Wave Systems

Infrared systems consist of a wireless microphone, infrared converter, and infrared receiver. The microphone converts the acoustical signal to an electrical signal that is then transmitted to the converter. The converter transduces the electrical signal to an invisible infrared signal and transmits it to a receiv-

Table V. Advantages and Disadvantages of a Sound-Field FM System

Advantages

- Provides benefit to all listeners in the room with hearing loss.
- Can provide benefit to children with SNHL while malfunctioning hearing aids or auditory trainers are being repaired.
- Often the most inexpensive procedure of improving classroom acoustics.
- Does not stigmatize certain listeners.
- Speakers/teachers overwhelmingly accept sound-field system once they receive an in-service on the instrumentation or use the equipment.
- Speakers/teachers report lessened stress and vocal strain during teaching activities.
- Parents and students overwhelmingly accept sound-field amplification systems.
- Can be used to enhance the auditory signal from other instructional equipment (e.g., television, cassette tape/compact disk players).
- High mobility for speaker and listener.
- Not susceptible to electromagnetic interference.

Disadvantages

- Might not provide adequate benefits in excessively noisy or reverberant listening environments.
- Primarily used only for abnormal hearers and listeners with milder degrees of SNHL.
- Loudspeaker arrangement and/or number of loudspeakers(s) must be appropriate.

er that is worn by the listener. The receiver, which also often serves as an amplifier, contains photo-detector diodes that pick up the infrared signal and transduces the infrared signal back into electrical energy. The electrical signal is then changed into acoustical energy and routed to the listener via an induction loop/hearing-aid telecoil setup, through headphones/insert earphones, or direct audio input (DAI). For optimal sound quality with these systems, the child must be in a direct line with the transmitter. Advantages and disadvantages of infrared systems are shown in Table VI.

Electromagnetic Induction Loop Systems

An induction loop system consists of a microphone connected via hardware or via an FM transmitter to an amplifier. A length of wire, which is wound around

Table VI. Advantages and Disadvantages of Infrared Systems

Advantages

- Worldwide use is high.
- Not susceptible to electromagnetic interference.
- Relatively inexpensive.

Disadvantages

- Because the infrared cannot penetrate solid barriers, listener must be in a direct line of sight with the transmitter.
- Cannot be used outside or in highly lit rooms, since infrared is susceptible to interference from sunlight.

a magnetic core under its installation, extends from the amplifier. This wire loop is typically placed around the perimeter of a classroom, but it can also be worn around the listener's neck. When an electrical current flows through the wire loop, it creates a magnetic field, which can be picked up by any device using telecoil technology, such as a hearing aid. Generally, induction loop systems require a hearing aid to have a telecoil that is sensitive enough to pick up the magnetic field throughout the classroom for good speech perception. It should also be noted that speech perception tends to decrease as the listener moves away from the induction loop. Advantages and disadvantages of large-area induction loop systems are presented in Table VII. [*Note:* Hendricks and Lederman (1991) recently developed a 3-D induction loop system designed to avoid many of the difficulties associated with traditional induction loop systems.]

Hard-Wired Systems

The oldest — and currently the most infrequently used — hearing-assistive devices are hard-wired systems. With hard-wired systems, a wire connects the microphone of the speaker to the amplifier and the amplifier to the receiver used by the listener. Thus, with hard-wired systems, there is a direct physical connection between the sound source and the individual. Because of the reduced mobility for both the speaker and the listener with these devices, they are generally not recommended for most listening environments. Advantages and disadvantages of hard-wired systems are shown in Table VIII.

Legislation for Hearing-Assistive Technology

It should be noted that a number of federal laws provide for the use of assistive technology for children in the classroom. For additional information on these laws, the reader should consult Crandell et al. (1995).

Table VII. Advantages and Disadvantages of Large Area Induction Loop Systems

Advantages

- Often least costly of the room amplification systems.
- Installation, portability, troubleshooting, and maintenance of such systems tend to be relatively easy.
- Hearing aid users already have receiver if their hearing aid contains a telecoil.
- High degree of electroacoustic flexibility (due to hearing aid telecoil).

Disadvantages

- Require functional telecoil that is sensitive enough to pick up the magnetic field throughout the room and/or incorporate a preamplifier.
- Require hearing aids (or some device with telecoil), which limits use for "normal hearers."
- Require hearing aids that contain telecoil option.
- Signal quality may decrease as the listener moves away from the induction loop.
- Reduced portability: For example, it is not practice to move such systems to accommodate outdoor activities.
- Number of rooms in a building that can be equipped with such technology may be limited, since "spillover" can occur across systems.
- Signal quality might be reduced by additional devices in the room that produce electromagnetic fields (and 60-Hz hum), such as florescent lighting and electric power lines

Classroom Listening and Speech Recognition Strategies

Even with the significant improvement in SNR offered by hearing-assistive technologies, speech perception in the classroom may be further improved by several simple modifications in teaching/teacher strategies, such as: (1) improving speaker-to-listener distance; (2) fostering visual communication enhancement; (3) using "clear" speech; and (4) learning to listen.

Improving Speaker-to-Listener Distance

Ensuring that the child receives the teacher's voice at an advantageous speaker-to-listener distance can diminish the adverse influences of poor classroom acoustics. At speaker-to-listener distances close to the teacher, direct sound dominates the listening environment. In the direct sound field,

Table VIII. Advantages and Disadvantages of Hard-Wired Systems

Advantages

- Inexpensive.
- May be useful in some hearing-impaired patients who might not be able to use conventional amplification (cognitive declines, physical disabilities, and/or severe manual dexterity difficulties).
- Installation of such systems tends to be relatively easy.
- Not susceptible to electromagnetic interference.

Disadvantages

- The U.S. Food and Drug Administration (FDA) does not specify hard-wired systems as medical devices. Therefore, there are no standards for the electroacoustic characteristics of such devices (e.g., gain, frequency response, SSPL90, harmonic distortion).
- Limited mobility for the speaker and/or listener.
- Installation costs can be high, particularly in an already-constructed building.

sound waves are transmitted from the teacher to the child with minimal interference from room surfaces. Direct sound pressure follows the principle of the inverse square law (ISL), which dictates that sound pressure levels decrease 6 dB for every doubling of distance from the sound source. Therefore, according to the ISL, the direct sound field is predominant only at distances close to the teacher. As the child moves away from the teacher, the indirect sound field predominates the listening environment. The indirect sound field originates at the critical distance of the room — the point in a room in which the intensity of the direct sound is equal to the intensity of the reverberant sound. In the indirect sound field, the direct sound from the speaker arrives at the listener initially, but it is followed by reverberated signals composed of the original wave that has now been reflected off the ceiling, walls, and floor. Several investigators have demonstrated that speech-perception scores will decrease until the room's critical distance is reached. Beyond the critical distance, perception ability tends to remain essentially constant in the classroom (Crandell, 1991; Crandell & Bess, 1986; Peutz, 1971). These findings suggest that speech-perception ability can be improved only by decreasing the distance between a speaker and a listener within the room's critical distance (e.g., as is achieved with small group instruction). These data also indicate that preferential seating might not assist speech perception if the child is not within the critical distance of the room. In typical classrooms, the critical distance is approximately 3–6 feet from the teacher.

Visual Communication Enhancement

Decreasing speaker-to-listener distance will also aid the child in a classroom in maximizing visual cues and speechreading skills. According to Schow and Nerbonne (1996), optimal speaker-to-listener distance for maximum speechreading is approximately 5 feet and decreases significantly at 20 feet. Several investigators have reported that the benefit of speechreading increases as a function of decreasing SNR (Erber, 1979; Middleweerd & Plomp, 1987; Rosenblum, Johnson, & Saldana, 1996). In other words, listeners often obtain significantly more information visually as the acoustical environment becomes more adverse.

"Clear" Speech

Another way to augment speech perception in the classroom is with "clear" speech. Clear speech refers to a process in which the speaker focuses his or her attention on a clearer pronunciation of speech while using a slightly reduced rate of speaking and a slightly higher intensity (Picheny, Durlach, & Braida, 1985a,b). Several studies have shown that clear speech can significantly improve speech perception in noisy and reverberant environments (Picheny et al., 1985a,b; Payton, Uchanski, & Braida, 1994; Schum, 1996; Crandell, 1998). Payton et al. (1994) demonstrated, for example, that the average improvement in speech perception when using clear speech was 20% for listeners with normal hearing and 26% for listeners with SNHL. Learning clear speech procedures shouldn't be an unreasonable burden for teachers or other speakers. In fact, speakers have been trained to continuously produce clear speech after only a minimal amount of instruction and practice (Schum, 1996).

Strategies for Improving Listening

Listening, a major component of the communication process, refers to the ability to detect, discriminate, identify, and comprehend auditory signals. Listening comprises 45% of daily communication for adults, while school children spend as much as 60% of the school day in this process (Berg, 1993; Rosenberg & Blake-Rahter, 1995). Research has shown that those who experience difficulty at any level of the listening process will find it more difficult to use auditory information in an efficient manner (Rosenberg & Blake-Rahter, 1995). Despite the importance of listening in room communication, the process is rarely taught to individuals with hearing loss. The reader should consult Crandell and Smaldino (In Press) for more detailed discussions on strategies for improving listening.

Efficacy Measures for Interventions to Improve Room Acoustics

Regardless of the procedure or procedures used to improve the acoustical environment, the efficacy of that procedure must be assessed. In other words, no matter how the improvement is attempted, whether through physical mod-

ifications and/or the use of assistive technology, a measurable outcome of the intervention will be required in order to prove whether the intervention was effective or not. Classrooms can be extremely difficult environments in which to conduct efficacy studies. Not only are teachers often unwilling to conduct intrusive and lengthy test procedures, but efficacy measures usually must be conducted during the school day. Despite these difficulties, several approaches have helped document the effects of intervention to improve acoustics on speech perception, listening, and learning in the classroom. One procedure in measuring efficacy of acoustical modifications in the classroom involves observing changes in academic achievement or on-task behaviors. Unfortunately, because these measures may be influenced by factors unrelated to the acoustic interventions, it is often difficult to use them to establish efficacy in the classroom.

Another procedure to measure efficacy is to compare speech-perception measures pre- and post-treatment. Researchers have used some of the more analytical speech test materials to pinpoint not only specific problems with a classroom's acoustics, but also perceptual differences between students in that classroom. Although speech-perception materials are commonly used, the link between speech perception, listening, and learning is not well established.

A final method for measuring efficacy is through subjective report questionnaires that obtain specific information on variables known to directly influence learning in the classroom. The most prominent of these questionnaires is the *Screening Instrument for Targeting Educational Risk* (SIFTER) (Anderson, 1989), in which the teacher observes and rates each student (or classroom of students) in five content areas: academics, attention, communication, class participation, and school behavior. The total score in each content area is then categorized as pass, marginal, or fail.

A preschool version of the SIFTER has also been developed to evaluate younger children (age 3 through kindergarten) (Anderson & Matkin, 1996). While originally intended as a tool to help identify students at risk for listening problems, it has proved to be useful in establishing efficacy of intervention in the classroom when used in a pre- and post-test experimental design. An extension of the SIFTER called the *Listening Inventories for Education* (LIFE) (Anderson & Smaldino, 1998) retains a teacher self-report questionnaire, but also adds a self-report questionnaire for the student. By obtaining direct input from the student on listening difficulties in the classroom, the overall validity of the subjective approach to efficacy should be improved.

Summary

It is well recognized that inappropriate levels of classroom reverberation and noise can deleteriously affect speech perception, reading/spelling ability, behavior, attention, concentration, and academic achievement. This chapter reviewed several methods to improve room acoustics, including acoustical modifications of the room, personal hearing aids, hearing-assistive devices, reduction of speaker-listener distance, enhancing visual communication,

"clear" speech procedures, and strategies for improving listening. Approaches were outlined that have been used for documenting the efficacy of acoustical modifications and room amplification in an acoustical environment.

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Afterword

Carl C. Crandell, Ph.D., and Joseph J. Smaldino, Ph.D.

We have emphasized throughout this monograph that the acoustical characteristics of a classroom are important variables that may affect the academic achievement of all children: those with normal hearing, those with various degrees of hearing loss, and those with specific learning disabilities. A review of the literature clearly indicates that inappropriate reverberation and/or noise levels in the classroom compromise not only the speech perception of many children, but also their reading/spelling ability, behavior, attention, concentration, and ultimately their academic achievement. Several studies in recent decades have suggested that for there to be satisfactory communicative efficiency in the classroom, ambient noise levels should not exceed 30–35 dB(A) and reverberation times should not surpass 0.4–0.6 seconds. Unfortunately, for various reasons, these acoustical conditions are rarely achieved in the typical classroom today. As Donna Sorkin noted in the Foreword, it is our hope that this monograph will be pertinent for many groups, particularly parents, adults with hearing loss, audiologists, educators of the deaf, school administrators, speech-language pathologists, architects, and acoustical engineers. By providing this information, we hope to play an important role in the continuing effort to significantly improve classroom acoustics, learning, and psychosocial development for the benefit of society's most valuable resource — our children.

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