Kids in Noisy Classrooms: What does the Research Really Say?

Karen L. Anderson, Ed.S.
Florida State University

The Federal rulemaking agency responsible for implementation of the Americans with Disabilities Act of 1990 has recently sought to define criteria for acoustic conditions to address the needs of persons with disabilities in learning environments. As a result, knowledge of the effects of inadequate acoustic environments on learning has become of increasing interest to groups such as educational administrators, architects, and audiologists. The purpose of this document is to review the body of research applicable to the effects of adverse acoustic environments on children's learning. The direct effects of background noise and reverberation on speech perception will be considered. In addition, the indirect effects of adverse listening conditions in the classroom will be reviewed. These include the effects of noise on health, the performance of specified tasks, attention, reading ability, and some information on open plan classrooms. This body of research supports the need to address the acoustics of the classroom environment so that all students can learn without detriment from the interfering affects of excessive noise and reverberation.

In a critical review of controlled classroom studies, Hartman considered collected articles primarily from the 1930s. A summary of the findings of these articles indicated that high levels of background noise were likely to be most disturbing when a pupil was engaged in tasks that demand higher mental processes. Based on his review, Hartman summarized that in the presence of high levels of background noise "The efficiency of all kinds of mental work, especially the more complex varieties, is generally noticeably lowered" (Hartman, 1946, p. 149). He also noted that, "even when, as frequently happens, able or highly motivated pupils maintain approximately the same level of achievement under noisy or 'silent' conditions, they succeed in doing so only by virtue of putting forth additional effort to overcome the new obstacles" (Hartman, 1946, p. 161). This author concluded that building of new schools in the post World War II construction period place appropriate acoustics high on the list of priorities "if teachers and pupils are to be spared the needless inefficiency of trying to go uphill with the brakes on" (Hartman, 1946, p. 161).

Despite the recognized importance of an appropriate classroom acoustic environment for over 50 years, there are no established federal standards for classroom noise or reverberation levels. The words of Hartman received little attention as can be evidenced in the 1995 General Accounting Office Report to Congress in which 28% of the respondents listed Acoustics for Noise Control as being unsatisfactory and rated acoustics as the number one environmental issue. Indeed, classrooms that are being designed today are a duplication of inadequate 50-year-old designs (Towne & Anderson, 1997). Simplistic classroom designs and even open-plan designs – with little consideration for acoustics – continue to attract school boards and architects who have a primary concern of fiscal responsibility (Crandell, Smaldino, & Anderson, 2000).

In the past few years there has been increasing attention on the effects of noisy classrooms on learning, as evidenced by the number of pertinent articles published, especially in the audiology and education fields. At least three reasons can be surmised for this increase in attention. First would be the public and governmental pressure for improvements in academic test scores, causing scrutiny in a variety of aspects of education. A second reason would be the bulge in school construction currently occurring in the United States to serve offspring of the baby boomers. The last such school construction boom occurred after World War II. Third, due to the advent of universal newborn hearing screening and the resulting flow of families receiving early intervention service, it can be observed that more parents are advocating for appropriate education programs for children with hearing impairment.

Parent involvement and concern over the affects of inadequate classroom acoustics on a child's learning has had a far-reaching affect. The United States Access Board, which develops guidelines for accessibility under the Americans with Disabilities Act of 1990, heard an appeal from a parent of a child with hearing loss who was not being served adequately in a noisy classroom. The Access Board agreed to study the problem of noisy and reverberant classrooms as part of the ADA to determine if children with disabilities were being underserved because of poor classroom acoustics (Nelson, 2000). In September 1999, the Access Board published a "Notice of Agency Action on Classroom Acoustics" in the Federal Register. Within this notice, the board emphasized that a noisy and reverberant classroom is as much a barrier to children with hearing loss as stairs are to those who use wheelchairs. As the United States moves toward defining criteria for adequate acoustic learning environments as part of the ADA, knowledge of the affects of inadequate acoustic environments on learning has become of higher interest to groups such as educational administrators, School Board members, architects, and audiologists. As the interest in the adverse effects of inadequate classroom acoustics gains momentum in the United States, it is hoped that this review will be useful when parents, professionals, and governmental interests ask the question, "What do we really know about how background noise and reverberation affects children's learning?"

Areas of Impact of Poor Classroom Acoustics

The affects of acoustics on perception, behavior, or learning have been studied by individuals in a variety of fields including audiology, acoustics, environmental health, medicine, and psychology. The purpose of this paper is to draw together studies from these varying fields and critically review the acoustics literature in three broad areas: (a) direct, or primary effects on speech perception; (b) indirect, or secondary effects on children's attention; and (c) reading acquisition. For the purposes of this review, preference was given to including investigations that meet the following criteria: (a) quantitative experimental studies from peer reviewed journals; (b) use of children under the age of 15 as subjects; (c) use of persons with normal hearing as subjects; (d) specification of how reverberation or background noise were measured; (e) identification or exclusion of subjects who learned English as a second language, had deficits in cognitive ability, or presented other disability conditions; and (f) management of the variable of socioeconomic status in some manner. However, some exceptions were made. Although children are the major focus of this report, studies were included that have only adult subjects, specifically for elucidation on the affects of noise on human performance of specific tasks. Brief mention is also made of the apparent affects of excessive noise on children's cardiovascular health. Several studies are mentioned that include findings for children with hearing loss as well as those with normal hearing as a means to contrast and emphasize the effects of adverse listening conditions on speech perception.

Speech Perception

Perhaps best known to the field of audiology are the investigations studying the impact of noise and/or reverberation on the accuracy of speech perception. This review will break down the speech perception literature into three areas: speech perception in noise, in reverberation, and the perception of speech in the presence of reverberation and noise.

Speech Perception in Varying Levels of Background Noise

Most speech perception studies have been laboratory studies rather than studies performed in classroom environments. Replication of field studies is difficult as specific acoustic characteristics of classroom spaces or measurement techniques are typically excluded from research reports. In addition, background noise that naturally occurs in a school setting is dynamic and changes in intensity and noise characteristics as activities occur throughout the day (Bradley, Reich, & Norcross, 1999). The dynamic nature of naturally occurring background noise in schools causes difficulty in replication of research investigations as the features of noise are not constant and the resulting inconsistencies in performance may be highly variable. Also, the signal-to-noise ratio (S/N) derived from the loudness of the teacher's voice over background noise is also dynamic throughout the school day (Bradley, et al., 1999). Hence, most authors investigating speech perception in noise introduce a constant level of a specific type of background noise and a constant intensity of test stimuli that can be used as a basis for replication.

In general, research indicates that the ability to perceive speech in noise depends on the intensity level of the speech in comparison to the noise at the listener's ear, the type of noise, the listener's innate cognitive potential, his or her knowledge of the phonemic basis of the language spoken, and the comprehension of the vocabulary used (Bronkhorst, 2000; Crandell, 1993; Elliott, Connors, Kille, Levin, Ball, & Katz, 1979; Finitzo-Hieber & Tillman, 1978; Mayo, Florentine, & Buus, 1997; McCroskey & Devens, 1975; Nober & Nober, 1975; Papso & Blood, 1989; Stuart & Phillips, 1997; Webster & Snell, 1983). Degradation of speech understanding occurs as background noise increases. This appears to be true for adults and children; however, the effects of noise on children's performance are more severe than on adult performance (Cooper & Cutts, 1971; Crandell, 1993; Elliott, et al., 1979; Fallon, Trehub, & Schneider, 2000; Finitzo-Hieber & Tillman, 1978).

Competing speech noise, such as babble, cafeteria noise, or noise that has a matched acoustic spectrum to that of the speech stimuli used, has a larger degradation effect than broader spectrum noise, such as broadband noise, white noise, or pink noise (Elliott, et al., 1979; Papso & Blood, 1989). When only the affects of noise are considered, continuous noise is more disruptive to the speech perception of young adults than interrupted noise (Stuart & Phillips, 1997), which is in agreement with findings in the adult human performance literature briefly summarized in this paper (Broadbent, 1979; Fisher, 1972; Woodhead, 1964; Salame & Wittersheim, 1978; Smith, 1985). As can be seen in the section of this paper that deals with the presence of high reverberation and speech, the effects of the type of noise are not always the same when different levels of reverberation are compared. Vowels are less fragile to noise interference than are consonants at low and moderate noise levels; however, at high noise levels the listener's auditory discrimination ability for all phonemes is at risk (Gordon-Salant, 1985; McCroskey & Devens, 1975).

When the performance of children who were not native English speakers was compared to native English-speaking children, there was a significantly greater detriment to speech perception of non-native speakers as the signal-to-noise ratio declined lower than +6 dB S/N (Crandell & Smaldino, 1996).

In summary, degradation of the performance of children's speech perception in background noise appears to be well documented. What is not clear is the degree to which children will perform at discrete ages between 5-12 years under conditions of (a) broadband noise typical of classroom air handlers versus speech babble typical of spillover from adjacent classrooms or the two in combination, (b) the performance of children with different levels of phonemic awareness or phonemic identification skills related to reading under differing noisy conditions, and (c) the use of context under different levels of noise (sentences versus words). Also, it is unknown if continuous noise is more disruptive than interrupted noise to the speech perception of children, as it is for young adults with mature auditory capabilities, and the degree to which varying reverberation times affect these abilities.

Speech Perception in Listening Environments of Varying Reverberation Times

Reverberation has been described as smearing, or distorting the temporal envelope of the speech signal (Bolt & MacDonald, 1949; Gelfand & Silman, 1979; Moncur & Dirks, 1967). Short-duration phonemes are more affected by reverberation than long-duration phonemes. The frequencies are attenuated typically at 6 dB/octave (Plomp, 1986), with the more powerful vowel sounds, that are less important to speech intelligibility, being more resistant to smearing of the temporal envelope. Also, in reverberant speech, final consonants are masked by delayed energy of preceding segments, which does not hold for initial consonants (Drullman, Festen, & Plomp, 1994).

The larger the number of sound reflections that occur and smear the speech signal within the listening environment, the greater the reverberation time. In small rooms (often smaller than typical classroom size), overlapping reflections act as a more uniform masking noise, which has a spectrum close to the speech signal. Confusions are similar to those made under noise masking (Bolt & MacDonald, 1949). While reverberation can be treated as a special case of masking noise, it is perceptually different. Noise can be easily noticed whereas moderate reverberation is more difficult to identify and has more subtle speech perception affects (Nabelek and Robinson, 1982).

When different age groups are considered, increases in reverberation cause decreases in phoneme identification across age groups (Neuman & Hochberg, 1983). The ability to identify speech in reverberant environments improves with increasing age and reaches asymptote at age 13 when performance approximates that of young adults (Neuman & Hochberg, 1983). A comparison of 10-year-olds to 27-year-olds in the Nabelek and Robinson (1982) study revealed a degradation in speech perception for both age groups despite differences in age-appropriate test materials. Ten-year-olds required a speech signal level 5 dB greater than 27-yr olds to obtain same accuracy in speech perception. Thus, data from studies of young adults cannot be assumed to be predictive of children's responses under the same adverse listening conditions. Or, from another perspective, reverberation time that is insufficient to interfere with adult perception may be a detriment to the speech perception of children.

Binaural hearing is superior to monaural hearing for normal and hearing-impaired populations (Moncur & Dirks, 1967). Binaural scores for 0.6-second reverberation time are superior to monaural scores for all age groups with 5 year olds showing the greatest binaural advantage. The far ear plays an important part in binaural listening superiority (Moncur and Dirks, 1967).

When considering the children ages 8-13 that participated in the study by Finitzo-Hieber and Tillman (1978), reverberation produced a statistically significant reduction in word discrimination for a group of children with normal hearing and a group of children with mild to moderate hearing loss. Children with hearing loss are affected to a greater degree by excessive reverberation times than are children with normal hearing (Finitzo-Hieber and Tillman, 1978; Nabelek & Pickett, 1974a). Under reverberant listening conditions, non-native speakers also experience significantly higher levels of speech degradation than native language speakers (Nabelek and Donahue, 1984; Crandell, 1994).

In reviewing the findings of reverberation affects studies, there is limited knowledge of the developmental effects of varying reverberation times for children of different ages. Also unknown is the degree to which contextual cues affect children's performance under varying reverberation times.

Speech Perception in Listening Environments with Varying Levels of Background Noise and Reverberation Times

There is a synergistic effect when background noise and reverberation co-occur that increases degradation of speech perception more than a if a simple additive affect were present (Bradley, 1986; Finitzo-Hieber and Tillman, 1978; Irwin & McAuley, 1987; Lochner & Burger, 1961; Nabelek & Pickett, 1974a,b; Yacullo & Hawkins, 1987). Deterioration in word recognition occurs with prolonged reverberation and increased noise (Bradley, 1986; Finitzo-Hieber and Tillman, 1978; Helfer, 1994; Irwin & McAuley, 1987; Lochner & Burger, 1961; Nabelek & Pickett, 1974a,b; Yacullo & Hawkins, 1987). Masking of speech by background noise is more pronounced at higher levels of reverberation time. This appears to be due to temporal smearing effects coming into play, even when the level of background noise is held constant (Lochner & Burger, 1961). Lower frequency early/late sound decay ratios have a strong influence on speech intelligibility. Due to this, the decay times of different frequencies in a room should be included in acoustical measures of classrooms and the relative presence of low frequency components in a room should be seriously considered in the overall effects of reverberation.

When considered alone, an increase in background noise of 10 dB SPL required the intensity of the speech signal to be increased by approximately 10 dB SPL for the speech to remain equally intelligible (Irwin & McAuley, 1987). When noise plus reverberation are present this same relationship does not hold true and a person's threshold for speech in quiet is a not as accurate a predictor of his or her threshold for distorted speech (Bistafa & Bradley, 2000; Irwin & McAuley, 1987).

Johnson (2000) found that children's consonant identification abilities in high noise or excessive reverberation reached adult-like levels at about age 14 years. However, in the combined condition of excessive noise and reverberation, children's consonant identification abilities were not found to reach mature levels until the late teenage years. The ability to identify vowels developed much earlier. Children with normal hearing identified 75.5% of vowels in quiet and 64.2% in noise. In contrast, these children were found to be able to identify 63.7% of consonants in a quiet setting and 28.2% in a noisy setting (Johnson, Stein, Broadway, & Markwalter, 1997). These results suggest that the ability to identify speech in the presence of reverberation and noise reach adult-like levels of performance at different ages for different components of the speech signal.

With longer reverberation times, impulsive noise was found to be more detrimental to speech reception than quasi-steady noise or speech babble (Nabelek & Pickett, 1974b). This finding was not in agreement with investigations of noise without reverberation interactions that concluded that speech noise had a greater deleterious affect on speech perception (Papso and Blood, 1989; Stuart and Phillips, 1997). Therefore, it is important to consider the amount of reverberation present in a room when evaluating the potential impact of the kinds of noise that may be present in a classroom.

Most investigations of speech perception in adverse acoustic conditions have used words or nonsense syllables without taking into account the listener's use of context as a means to compensate for fragmented speech perception. The context of a sentence provides informational redundancy that enables the listener to perceive words at lower intensities or lower signal-to-noise ratios. An investigation using sentence materials found the decrement in performance with decreasing S/N was not consistent at each level of reverberation (Yacullo & Hawkins, 1987). The facilitating effect of context was not apparent and appeared to be comparable or poorer than when assessed with monosyllabic words. In contrast, Theodoridis and Schoeny (1988) compared responses of words and sentences presented at various signal-to-noise ratios. When stimuli were presented monaurally in noise, the authors found that sentences contributed a substantial enough amount of contextual information to result in consistently improved scores over single words. A 1990 study investigated performance differences of listeners responding to male and female NU-6 materials in quiet and noise (Wilson, Zizz, Shanks, & Causey). In broadband noise at a 0-dB signal to noise ratio, recognition performance for male-speaker NU-6 materials typically ranges from 50% correct to 70% correct. At 0-dB S/N ratio, the recognition performance for the female speaker in broadband noise was at a performance level of <10% correct. To obtain 50% correct the S/N had to +11 dB and to obtain 70% correct the S/N had to be +16 dB. To obtain equal detection and equal recognition performances on the two versions of NU-6 materials, the female-speaker version had to be presented at sound pressure levels that were 5 dB higher (detection) and 15 dB higher (recognition) than the sound pressure levels required by the male talker version. For the female speaker, the major peak in the speech spectrum that occurs between 188-262 Hz probably reflected a smeared fundamental frequency. Therefore, the information contained in the frequency regions higher than 300 Hz in the male version were up to 14 dB higher in intensity than this region of the speech spectrum in the female version of the NU-6 materials. Thus, classroom acoustics investigations that utilize male-speaker versions of materials may under-represent the degree of speech degradation under inadequate acoustic conditions for the majority of school classrooms, which have a female teacher.

Persons with hearing impairment do not perform as well as normal hearing subjects under all conditions of reverberation and background noise (Finitzo-Hieber & Tillman, 1978; Irwin & McAuley, 1987; Nabelek & Pickett, 1974a,b). This is possibly because hearing impaired listeners perceive speech in a fragmented manner and cannot follow the changes in the temporal envelope of an acoustic waveform with the accuracy of normal listeners (Irwin & McAuley, 1987).

Based on research findings in 1986, background noise in unoccupied classrooms of average size (300 m3) was judged to be acceptable if it did not exceed 34 dBA (Bradley, 1986). A recent formula for developing speech intelligibility metrics for classroom acoustics has defined a maximum reverberation time of 0.4 - 0.5 seconds and a maximum background noise level for classrooms of 20 dB and 25 dB for respectively ideal and acceptable classroom acoustics for normal hearing listeners (Bistafa & Bradley, 2000). For adolescents, with every increase of 1 sec of reverberation time, there was found to be a decrease of approximately 13% in word recognition (Bradley, 1986). Using different stimuli, younger children who did not have mature auditory systems had a respective decrease of 19.2% (Finitzo-Hieber & Tillman, 1978).

In summary, the detrimental influence of reverberation time depends on both the age of the subjects and the level of background noise present (Bradley, 1986; Finitzo-Hieber & Tillman, 1978; Irwin & McAuley, 1987; Nabelek & Pickett, 1974a,b; Yacullo & Hawkins, 1987). The most complete data depicting the effects of varying reverberation times and levels of background noise was completed with children ages 12-13, who had relatively mature auditory systems (Bradley, 1986). Unknown are the results of systematically varied reverberation times and levels of background noise for school-age children ages 5-12 years. Also unknown is the ability of children to compensate under varying acoustic conditions if contextual cues are available in comparison to single words or nonsense syllables although the influence of semantic context has been found to increase with age (Elliott, 1979; Stelmachowicz, Hoover, Lewis, Kortekaas, & Pittman, 2000).

Effects of Noise on Health

Numerous studies have been performed investigating the impact of noise on children's health. Children living and attending schools in very noisy areas, such as flight paths (greater than 60 dBA) have higher systolic and diastolic blood pressure (Bradley, 1986; Cohen, Evans, Krantz, Stokols, & Kelly, 1981; Elliot, 1979; Haines, Stansfeld, Job, Berglund, & Head, 2001; Passchier-Vermeer & Passchier, 2000; Regecova & Kellerova, 1995; Semotan & Semotanova, 1969). The older the child, the more apparent the influence of noise on blood pressure. The critical age at which blood pressure was found to became significantly higher was after a child had been living in a noisy area for a minimum of 5.5 years (Cohen, Evans, Krantz, & Stokels, 1980). Cardiovascular effects may be greater for children than for adults (Berenson, 1980; Cohen, Glass, & Phillips, 1979), however excessive noise was not found to be associated with mental health problems (Evans, Hygge, & Bullinger, 1995; Haines, et al., 2001).

Effects of Noise on Social Behavior, Fatigue, and Attention

Anyone that has ever tried to have a conversation in a noisy room will recognize that the effort it takes to listen carefully in a sea of background noise is fatiguing and that the ability to attend with such intensity wanes. Several studies considered these aspects of communication in noisy environments and their relation to social behavior.

Noise causes a person to focus attention on the most critical aspects of a situation, to the neglect of subtle interpersonal social cues (Cohen & Lezak, 1977; Cohen & Weinstein, 1981; Crandell & Smaldino, 1996; Passchier-Vermeer & Passchier, 2000). A restriction of attention affects the processing of less relevant social as well as nonsocial cues. Thus, noise may cause people to oversimplify and distort perceptions of complex social relationships.

Fatigue was indirectly investigated in a university setting (Persinger, Tiller, & Koren, 1999). A university psychology class was held in a recently remodeled room with high fan noise that cycled on/off every 5 seconds. Students were given a self-report questionnaire inquiring about their levels of concentration and fatigue after a 3-hour lecture with and without fans during a 3-hour lecture. These questionnaires revealed that students felt they experienced greater fatigue when fans were operative. The authors suggested that persistent interruption of attention could result in a negative affect to the teacher and course material and that this could be manifested as reduced attendance. Another study (Jerison, 1959) found alertness decrease in vigilance task after 1.5 hours in noise

A variety of studies have revealed that in a noisy setting, the most critical task is attended to by the listener, at the cost of not attending to more minor tasks (Cohen & Lezak; Cohen & Weinstein, 1981; Smith, 1991; Zentall & Shaw, 1980). Active monitoring tasks were impaired by noise, but tasks performed passively were unimpaired (Broadbent, 1958; Broadbent, 1978; Hamilton, Hockey, & Rejaman, 1977; Hockey & Hamilton, 1970; Park & Payne, 1963; Poulton, 1977). In other words, background noise could be expected to interfere with a student's concentration when listening to correct math answers and checking their own paper for correctness, but not during an art activity when there is not an active listening component.

Persons in classrooms that have excessive noise levels have been found to have greater inflexibility and were unable to deal efficiently with changing task demands (Dornic & Fernaeus, 1982; Smith, 1991). Considering all of the transitions between subjects and activities that typically occur in a school classroom, this finding could be interpreted to mean a class with excessive noise may take longer to transition between subjects or take longer to orient to new activities. A student self-report study conducted with university students identified a perception of less student participation and less attention comparing performance under noise-induced and no-noise conditions (Persinger, Tiller, & Koren, 1999).

A 1980 study (Zentall & Shaw, 1980) considered the effects of noise on children with diagnosed attention deficit disorder. This study compared a control group and attention deficit group of middle-class 2nd graders. The investigation found that when performance in noise was compared to performance in relative quiet, the children with attention deficit disorder were more active in noise, had more math errors and more errors when asked to cross out all e's in a given paragraph. During familiar tasks, the control children appeared to benefit from high noise. Initially, when difficult tasks were performed both groups of children had higher error rates in noise than in quiet.

Noise as an annoyance has also been studied (Kjellberg & Skoldstrom, 1991; Semotan & Semotanova, 1969). Meaningless, constant broadband noise has been found to be least annoying, especially at low intensity levels. High intensity levels of noise and the presence of speech noise have been found to be most annoying (Eysenck & Eysenck, 1979; Slater, 1968; Smith, 1985; Wilding & Mohindra, 1983). Accuracy between performance in broadband noise versus speech noise is related to the difficulty of the task and the demands of the task on verbal processing (Broadbent, 1958, Broadbent, 1978; Eschenbrenner, 1971; Glass & Singer, 1972; Graham & Slaby, 1973; Hamilton, Hockey, & Rejman, 1977; Hockey & Hamilton, 1970; Park & Payne, 1963; Percival & Loeb, 1980; Poulton, 1977; Teichner, Arees, & Reilly, 1963; Tinker, 1925). Excessive reverberation in combination with background noise also has a synergistic affect that may change the level of annoyance of different types of background noise. As mentioned in the previous section on noise and reverberation, with longer reverberation times, impulsive noise was found to be more detrimental to speech reception than quasi-steady noise or speech babble (Nabelek & Pickett, 1974b).

The affects of noise on children's distractibility and concentration have also been investigated. Higgins and Turnure (1984) found that preschoolers were much more susceptible to distractibility, and glanced about more often in low and high (60/80 dBA) noise, as compared to 2nd or 6th graders. The 6th graders were able to focus attention, resisted glancing about, and had fewer errors than the other groups. Whereas, 2nd graders had more errors in noise than 6th graders for easy and difficult tasks, but the difficult task resulted in more errors even in low noise. Results of this study could be interpreted as meaning there is a developmental change in the ability to direct attention to an arbitrarily assigned task in the presence of extraneous stimulation. For the groups of older and younger children, the "learning phase" of a task increased the demand on attention. Children that frequently glanced away from the task performed poorly on the learning task. For these ages, "glancing" was a reliable predictor of "nonattention" and "nonlearning" as the amount of extraneous stimulation in the situation increased.

Students in two schools in Spain were studied (Sanz, Garcia, & Garcia, 1993). The students in the school that was exposed to excessively high traffic noise levels were found to perform consistently poorer on tests of attention as compared to matched students in a quiet school.

In a classic study by Cohen, Evans, Krantz, & Stokols (1980), the affects of noise on children's distractibility and concentration were examined. This study, often called the LA airport study, matched 3 quiet schools to 3 schools in the Los Angelos airport flight path. Students were matched for socioeconomic status, race, grade, and the education level of their parents.

In addition to other measures, students were required to cross out e's in a two-page passage from a 6th grade reader in the presence of an audiotape of a man reading a story and also in quiet using an alternate reading passage. The authors found that children from noisy schools who had lived in neighborhood for less than 2 years were less distractible than quiet school children. Once children from noisy schools had lived in noisy conditions for more than 4 years, they were found to be more distractible than those students from quiet schools. The authors commented, "At first, children attempt (somewhat successfully) to cope with noise by tuning it out. Later, as they find the strategy is not adequate, they give up." (page 239).

A wide variety of studies have considered the effects of noise when individuals are performing tasks. Almost any task in which a person has to react only at certain definite times, receives a clear warning of the need for reaction, and receives an easily visible stimulus is unaffected by continuous noise, such as a ventilation fan (Cohen & Weinstein, 1981; Park & Payne, 1966). To apply this to a classroom situation, there will be little effect in a classroom from continuous ventilation fan noise as long as well-learned tasks are being performed, and the teacher is diligent about verbally cueing students to attend and provides multiple visual cues. The presence of novel or unusual noise will interfere with efficiency on the performance of most tasks (Park & Payne, 1963). A similar effect occurs when accustomed continuous noise ceases (Slater, 1968). However, learning new information requires a higher level of student engagement than the performance of well-learned tasks. Performance on complex tasks deteriorates, while performance on simple tasks remains the same in the presence of noise (Gawron, 1982). In other words, when noise is distracting, performance decreases on complex tasks. When noise is present, a greater amount of effort must be applied to primary learning tasks at the expense of less important cues (memorize/recall; visual monitoring while listening) (Slater, 1968). Conversely, vigilance, monotonous, or motor tasks seem to improve under low-level noise (Smith, 1991).

It has long been assumed that persons in noisy situations will adapt to their environment. In reality, the reverse is true (Cohen, Evans, Krantz, Stokols, & Kelly, 1981). Indeed, the evidence indicating cardiovascular and attention affects occurring after several years of exposure to excessive noise supports the notion that adaptation does not occur (Cohen, Evans, Krantz, & Stokols, 1980). In general, our response to any particular noise is determined by physical properties of the noise (speech versus white noise), its meaning (i.e., competing conversation), and characteristics of the individual, including his or her perceived control over the noise (Glass & Singer, 1972; Krantz, Glass & Snyder, 1974; Seligman, 1975).

The Special Case of Open Plan Classrooms

Considering the cyclical resurgence in popularity of open plan classrooms during the past 35 years, only a surprisingly small number of research studies can be found describing the affects of noise from adjacent learning spaces. The three studies presented in this section reflect how teachers cope with open plan classrooms, student anxiety, and the changes in teaching style.

In general, teachers in open plan classrooms adjust curricula and teaching methods to cope with unwanted or potential disruptions (Ahrentzen & Evans, 1984). Teachers in open classes were found to cope with environmental noise by changing their curricula to prevent distraction to other classes. Eliminated were chalkboard races, task games, video activities and skits - all of which excite and activate learners (Ahrentzen & Evans, 1984).

Another study attempted to determine the affect of open versus traditional plan classes on student anxiety (Cotterell, 1984). Students in open plan schools were, (1) more anxious about performing competently in front of classmates, (2) more apprehensive about getting schoolwork completed correctly, (3) scored higher on schoolwork anxiety, (4) scored lower on being able to locate classes, know rules, etcetera, and (5) immature students experienced the greatest amount of interpersonal anxiety.

Cotterell (1984) also considered teaching style. Teaching styles used in traditional vs. open plan classes were dramatically different. Teachers in open plan classrooms were more likely to make students responsible for their own learning in activities, but when students needed help, teachers told students rather than eliciting their knowledge by interactive approaches. There was a distinctive pattern of lecture then group work, which had less discussion and seatwork than traditional classroom approaches. Transitions occurred more often and lasted much longer. There was more effort needed by the teacher to manage the class during transitions. In addition, more off-task behavior and peer-talking were observed in the open plan classes.

Gump and Good (1976) considered the amount of time students spent in nonsubstance activity (e.g., waiting, moving, getting organized) at two traditional and two open-space schools. Students in grades 1 and 2 in open plan schools spent a much larger percentage of school time in nonsubstance activities compared to traditional schools. A similar difference was found for 5th and 6th graders, although the difference was not as great.

Most of the research on open plan classrooms is confounded due to definitions of open plan spaces and teaching approaches. The fit between teacher program and classroom environment, perceptions of what is expected to occur in a classroom, and the physical features that influence this perception need to be addressed in studies of this area as well as the need to study other behavioral outcomes than achievement (e.g., participation, persistence, substantive activity, and distraction) (Ahrentzen, Jue, Skorpanish, & Evans, 1982).

Noise Effects on Achievement

Reading Achievement

There are several well-known studies on this topic. A study conducted in New York (Green, Pasternack, & Shore, 1982) compared students from schools in flight paths to schools in quiet neighborhoods. Students were matched for socioeconomic status, race, gender, hearing loss, mother's education level, and English as a second language status. Performance in higher-noise schools was associated with poorer reading and speech perception, but performance errors were unrelated to perception of embedded phonemes. The significance of this finding is to illustrate that chronic noise is linked to reading deficits, and performance errors are not due to masking noise during the research testing session. Noise was found to be a significant predictor of reading scores, independent of the controlled variables.

The Munich Airport Study (Evans, Hygge, & Bullinger, 1995) found reading comprehension and long-term memory were impaired in 3rd and 4th grade children attending schools around the old Munich airport. Reading comprehension improved after the airport was closed. Reading comprehension deteriorated in children in schools near the new airport. The study was careful to match subject by socioeconomic status of students from these two schools.

The New York Airport Study (Evans & Maxwell, 1997) compared schools in a different manner. There are three airports in the New York area. The New York schools were grouped for research purposes based on five noise contours determined for airport flight paths. Quiet and noisy schools were rigorously matched by their proportion of students with low socioeconomic status, student absentee rates, teacher experience, and teacher education. Once the schools were matched the reading achievement test scores for grade 2 through grade 6 were analyzed. This analysis identified a higher percentage of students in noisy schools reading 1-2 years below grade level. This delay was statistically found to be attributed to the noise contour level. As such, the actual level of reading impairment in the different noise exposure groups could be directly estimated from the noise dose-response curve. What was not made clear by this study was the amount of noise allowable before a decline in reading achievement could be predicted.

The Heathrow Airport Study (Haines, et al., 2001) very recently compared students from two schools who were matched for age, socioeconomic status, and use of English as a second language. Chronic aircraft noise exposure was found to be associated with higher levels of annoyance, and poorer reading comprehension. This study also tested student cortisol (stress hormone) secretion levels. Exposure to continuous excessive noise levels was not associated with mental problems or raised cortisol secretion. There was an association found between noise and reading. This association could not be accounted for by annoyance, social class, socioeconomic status, main language, or the level of acute noise exposure.

Interestingly, the Paris Airport Study (Moch-Sibony, 1984) found that students in schools without soundproofing that were on the airport flight path had poorer auditory discrimination skills and less tolerance for frustration; however, no reading effects were identifiable compared to socioeconomic matched controls from schools with soundproofing that were in the flight path.

Cohen, Glass, and Singer (1973) conducted a study of children in grades 3-5 that were living in a high-rise apartment on a busy expressway. When tested individually in a quiet room of their school, the children living in noisier (lower floor) apartments showed greater impairment in reading ability and auditory discrimination than those living in quieter (upper floor) apartments. The correlation between noise and auditory discrimination deficits increased with length of residence. The effects of race, socioeconomic status and hearing loss were ruled out.

An extensive study examined the affects of highway noise on students in Los Angeles schools (Lukas, DuPree, & Swing, 1981). Results suggested that noise had a more systematic effect upon sixth graders than upon third graders and that noise appears to have more predictable effects upon the skills involved in reading than those in mathematics. The learning spaces with higher Articulation Index values had a correlated higher score in reading performances, whereas there was no significant correlation for mathematics. Higher community noise also was correlated with lesser achievement in reading. Interestingly, when these results were interpreted it was found that there was an apparent trade-off between noise levels in the community and those in the classroom. If the community is quiet, more noise in the classroom can be tolerated without appreciable effect upon reading. For the third graders studied, a 10 dB increase in community noise level was equivalent to about a 20 dB increase in classroom noise level. Considering classroom noise levels alone, the effects were more pronounced for sixth graders than for third graders as evidenced by a decrease of about 1.5 grade units for every 10 dB increase in average classroom noise. Community noise levels had less effect, with about a 0.9 grade unit decrease for a 10 dB increase in noise level.

The New York Train Study was conducted in 1975 (Bronzaft & McCarthy). The school studied was parallel to the tracks of an elevated train. Trains passed the school an average of every 4.5 minutes, increasing the noise level on that side of the building from 59 to 89 dBA. Aggregate reading scores were compared for 3 years for grades 2, 4, and 6. A comparison was made between students attending classes on the noise-side, and non-noise side of building for those years. Students on the noise-side had poorer reading achievement, with lags averaging 3-4 months and ranging from 3-11 months. There was no analysis of scores for children in noise-side classes for multiple versus single years. Half of the students were considered to be of low socioeconomic status and there was a 25% mobility rate. It can be presumed that if only students that had been educated in classrooms on the noisy side of the building were compared to students educated in classrooms on the relatively quiet side of the building that the differences in reading achievement between the two groups would be more pronounced.

In 1983, Brady, Shankweiler, and Mann compared poor readers to good readers under two noise conditions. Poor readers made significantly more word recall errors while listening to speech in noise, but did not differ in perception of speech in quiet, or in environmental sounds (audio tape of dogs barking, door bells, etcetera). It was more common for poor readers to miss stop consonants, likely due to obscured acoustic features from noise masking. The authors concluded that poor readers could process speech signals adequately, but required a higher quality of signal (higher S/N) than good readers for error-free performance.

Other Areas of Achievement

McCroskey and Devens (1975) considered how an increase of 15 dB SPL of ambient white noise introduced in a classroom setting could impact student performance (e.g., an air conditioner). The children in grades 5 and 6 tested in classrooms with additional noise showed impaired auditory discrimination, visual motor skills, and visual discrimination as compared to control classes.

Two groups of 6th graders were compared for Performance on the Sequential Tests of Educational Progress (STEP) Reading Test and the Standard Progressive Matrices (Edmonds & Smith, 1985). The students were divided into two groups based on their cognitive ability being above or below the 50th percentile. Recorded classroom noise was introduced at 40 dBA and 70 dBA. On unfamiliar tasks the higher level of noise affected both groups. On familiar reading tasks, the higher level of noise interfered with performance of higher IQ students but not lower IQ students. In a similar study, when Patton and Offenbach (1978) considered the performance of learning disabled students, children with learning disabilities made more errors than children without learning problems on recognition memory tasks in 60 dBA of competing speech. When presented tasks in white noise there was no difference in performance between groups.

Learned Helplessness

Seligman (1975) stated that a psychological state of helplessness frequently results when a person continually encounters events that he or she has no control over. The state of helplessness includes a perception of lessened control over one's outcomes and a decrease in one's motivation to initiate new responses. Multiple studies have found that children or adults in noisy environments give up on a difficult puzzle task more readily than children or adults in quiet environments (Ando & Nakane, 1975; Cohen, Evans, Krantz, & Stokols, 1980; Downs & Crum, 1978; Hiroto, 1974; Hiroto & Seligman, 1975). In the studies of children, students are given an insoluble puzzle and a soluble puzzle. The index of motivation is considered to be the number of attempts or the length of time spent to solve the insoluble puzzle, or the completion rate of students solving the solvable puzzle after having been given the insoluble puzzle. Learned helplessness is inferred by the rate the children "gave up" on one or both puzzles. For example, in a study by Cohen et al, (1980) the children from noisy schools were found to fail to complete the soluble puzzle following the insoluble puzzle and were more likely to give up than their quiet-school counterparts (53% failed versus 36% failed).

A general deficit in task performance on the puzzle task and increased distractibility support the hypothesis that prolonged noise exposure affects cognitive processes. The "giving up" effect appears to continue over time, with children from noisy schools being less likely to persist when required to perform challenging tasks. This appears to be especially true for children educated in noisy classroom conditions for more than three years (Cohen et al., 1980). These findings held true for studies controlling for the affects of race, socioeconomic status, and hearing loss (Cohen et al., 1980; Glass & Singer, 1972; Krantz, Glass, & Snyder, 1974).

Cumulative Learning Effects

In 1979, Green investigated the cumulative effect of excessive noise on learning. A positive correlation was found between the noise level in the school as determined by a noise contour map and the percentage of 2nd - 6th grade children scoring 1 or more years below grade level (controlled for socioeconomic status). Children with low aptitudes in flight-path schools showed a cumulative deficit in tested achievement compared to matched children in quiet schools, however, these differences did not reach statistical significance until 10th grade (Maser, Sorensen, & Kryter, 1978). Similarly, Lukas, et al. (1981) suggested that a greater systematic effect of highway noise upon sixth graders as compared to third graders might have reflected some cumulative interaction between noise and achievement.

Disruption to Teaching and Learning

The greatest complaint by teachers of aircraft, traffic, or train noise was the interference in teaching (Crook & Langdon, 1974; Ko, 1979). Teachers had to pause during high noise, thereby losing momentum and student interest. Teachers' comments included: "Contagious nature of behavior manifesting distraction caused by noise" and "A wave of fidgeting which spreads through the room during periods of high noise" (Crook & Langdon, 1974, page 229). Some of the delays in reading and/or achievement have been suggested to be related to less teaching time for students due to disruptions from noise (Cohen & Weinstein, 1981; Crook & Langdon, 1974).

Does "Fixing" Room Acoustics Really Help?

A study performed in 1981 (Cohen, Evans, Krantz, Stokols, & Kelly, 1981) found that 3rd grade children had better math scores after being educated one year in abated classrooms compared to those educated in nonabated classrooms. A similar pattern was found for reading scores. Children in noise-abated classrooms also reported less difficulty via questionnaire. A 1981 follow up to the 1973 New York elevated train study (Bronzaft, 1981), revealed that the reading scores on the noisy side of the building improved to equal those from students on the quiet side of the building one year after rubber noise control pads were installed on tracks.

The Munich Airport Study (Evans, et al., 1995) performed 3 waves of testing of children in the schools closest to the old airport prior to its closure and the students in the school closest to the new airport after it was in use. Deficits in performance in the areas of long-term memory, reading, and motivation were identified for students near the old airport prior to its closure. When the a new Munich airport was built, scores of students attending the schools in proximity to the old airport improved in long-term memory, reading and motivation, and that deficits in these same areas developed in the children that were then being educated by the new airport.

In summary, the presence of excessive noise appears to be detrimental to the acquisition of reading skills. What is unknown is the specific threshold intensity level of noise (and what types of noise) at which children's speech perception, auditory discrimination, and eventual acquisition of reading skills begin to be affected.

Conclusion

Efforts to gain acoustical improvements in schools have been stymied because inappropriate acoustics are not as obvious as physical obstacles (Sorkin, 2001). The existence of acoustical standards, such as those under consideration by the United States Access Board, would increase the likelihood that new or renovated school construction would incorporate favorable acoustics. Real change in classroom acoustics is more likely if the affects of acoustic interference on behavior and learning were more widely recognized by architects, educators, educational administration, school board members, and legislators. The studies reviewed agree in one general conclusion: poor acoustics in the learning environment are detrimental to student performance. The following information can be concluded based on review of the literature:

1. The presence of background noise and/or reverberation has an adverse impact on the speech perception of children, with and without hearing loss or other challenges to learning (e.g., English as a second language, attention deficits, learning disabilities).
2. Children up to the age of 13 to 15 years are more adversely affected by acoustic interference than are adults.
3. Children do not habituate to learning under adverse listening conditions.
4. Background noise and reverberation are most detrimental when students are learning unfamiliar or complex information. This effect is greater for children with lesser intellectual capacities or other learning challenges. Continuous background noise or instrumental music may be of some benefit to student performance of well-practiced activities.
5. Children educated in high levels of background noise tend to give up faster than their peers from relatively quieter classrooms when they are faced with challenging activities and they are less flexible and more resistant to changes in their environment.
6. How well a child is able to pay attention in the presence of adverse listening conditions depends on the type and loudness of the noise, and the complexity or familiarity of the task. Noisy learning environments may be more fatiguing. In noisy classrooms, individuals are less attentive to social cues as their focus of attention on the primary learning activity is increased in response to the acoustic interference. This leaves fewer mental resources for subtle interaction cues. It has been suggested that children who are continuously surrounded by unwanted sounds may be more likely to ignore all sounds, whether relevant or not.
7. The impact of different types of background noise can differ based on the amount of reverberation present in the learning environment. In rooms with high reverberation, interrupted or impulsive noise may have a greater affect on speech perception. In rooms with moderate or low reverberation, continuous noise may effect a speech perception more significantly. Overall, linguistic interference (i.e., speech interference from adjacent spaces) appears to be most deleterious to children's speech perception.
8. The best speech perception can be obtained by an individual with two functional ears listening in a room with a short reverberation time (0.4 – 0.5 seconds), a signal-to-noise ratio of +15 dB, and an acceptable background noise level of 25 dB. These criteria have been derived primarily from two studies: (a) by the results of an extensive study of the performance of 12-13-year-old children using single, rhyming words (Bradley, 1986), and (b) application of speech intelligibility metrics that take into account sound reflections and background noise in the room (Bistafa & Bradley, 2000). Neither of these approaches considers the listening needs of younger children with immature auditory systems listening to single words or when contextual information from sentences is available.
9. There is little empirical evidence about the degree to which contextual information, such as that available from sentences, assists children's understanding in adverse listening conditions. Almost all speech perception studies with children have been performed using single word stimuli.
10. Use of simulated reverberation in studies, although convenient, may have incorrectly estimated the effects of reverberation on speech perception.
11. Even when parent education level, socioeconomic status, and the influence of other languages spoken are ruled out, it is still evident that chronic noise exposure is linked with reading deficits in children. Noise affects speech perception, which in turn appears to affect language processing and auditory discrimination, and has a subsequent impact on the development of reading skills. Children who are poor readers are more affected than their peers with typical reading ability when listening to speech in noise. When acoustical modifications are made to noisy classroom, pre-reading and reading skill development has been found to improve.

Recommendations for Future Research

The research findings on children's responses under noisy or reverberant classroom listening conditions support the supposition of deleterious effects, but are not complete in their investigations of all areas.

First, the most complete investigation to date on the effects of varying levels of signal-to-noise and reverberation on speech perception was Bradley's 1986 study, completed using 12-13-year-olds with essentially mature auditory systems. Some of the research findings presented in the speech perception section would lead us to believe that younger children would have substantially greater difficulties performing under varying levels of background noise and reverberation than seventh grade children. Age effects of varying levels of background noise and reverberation are vital, especially if criteria for classroom acoustics are established and enforceable under the Americans with Disabilities Act of 1990. For classroom acoustics criteria to remain unchallenged, empirical evidence may be required to support the necessity of criteria for specific age groups. For example, empirical evidence illustrating the need for a minimum reverberation time of 0.6 seconds rather than 0.7 seconds for children in high school, who have mature auditory systems, as well as primary school children in preschool through grade two. Studies of time-on-task or and other measures of student attention at these same varying levels of reverberation and background noise would strengthen the empirical evidence supporting the need for acoustic controls according to specific criteria.

Second, only a limited number of studies on children could be identified that used sentential material. Verbal instruction is typified by a continuous speech stream that is rich in contextual information. It is unknown to what degree the availability of contextual information assists children in understanding speech under degraded listening conditions. We do not know if there is a signal-to-noise threshold at which contextual information is no longer of benefit to speech understanding. It is of interest to identify how children at different ages perform under context versus no-context situations. If there were only limited financial resources to improve classroom acoustics in existing schools, empirical evidence supporting the necessity of addressing the listening environments in a few, some, or all grades would be of value to education administrators.

Third, the maximum 'dose' or threshold of signal-to-noise and reverberation allowable that will not adversely affect reading acquisition is unknown. Although Green et al. (1982) found that the percentage of students reading 1-2 years below grade level increases with the level of noise exposure, these findings were not interpreted in a manner that identified specific dB levels of background noise allowable for a certain percentage of students to achieve grade-equivalent reading levels, while controlling for extraneous variables.

Fourth, not all adult research findings have been replicated with children. Most conclusions on the different effects of the types of noise have largely been inferred from adult studies or not investigated in a systematic manner for children. In addition, noises typical of 'real-life schools' have not been the focus of this type of research. For example, what are the performance differences in children when they are listening in the presence of noise similar to air handlers in ventilation systems (broadband continuous noise), including those that cycle on and off frequently, and speech interference, such as that from adjacent classrooms? Similarly, is continuous noise more disruptive than interrupted noise to the speech perception of children at varying reverberation time as it is for young adults?

Finally, the failure of field studies to specify reverberation times or measurement techniques prevents replication. The dynamic nature of background noise present in schools makes this variable difficult to control in a rigid enough manner to allow valid comparisons between classrooms or schools. If wide-reaching studies concerning age effects and varying levels of reverberation and noise are to be performed, strict experimental controls of background noise and reverberation times must be imposed. Simulated noise and reverberation have been used by some researchers out of convenience and the desire to control the natural dynamics of classroom noise. Lab studies that have used simulated reverberation may have incorrectly estimated the responses of participants under actual reverberant listening conditions. Simulation is a convenient approach to studying classroom listening problems, however, simulation of reverberation has been found to identify a greater deleterious effect on the intelligibility of speech as compared to intelligibility under real reverberation. The two areas hypothesized as being responsible were nonexponential decay of the simulated reverberation and nonrandom distribution of reflections. Future research designs utilizing simulation of reverberation and signal-to-noise ratios must ensure that these identified deficits have been adequately addressed to provide a more natural simulation of reverberant conditions.

It is hoped that this review of studies of acoustic degradation effects provides a cohesive overview of what is known to date about the affects of background noise and high reverberation times on the speech perception, attention, and reading acquisition of young learners. There are unanswered questions that challenge researchers to further explore and explain these effects. With the prospect of establishing national criteria for classroom acoustics, a new age of interest in the affects of poor acoustics on learning will continue to emerge. The fields of audiology, acoustics, environmental health, education, and psychology must meet these challenges to fill the gaps in the existing research for the betterment of educational performance throughout the United States.

References

Ando, Y., & Nakane, Y. (1975). Effects of aircraft noise on the mental work of pupils. *Journal of Sound and Vibration, 43*(4), 683-691.

Ahrentzen, S., & Evans, G.W. (1984). Distraction, privacy, and classroom design. *Environment and Behavior, 16*(4), 437-454.

Ahrentzen, S., Jue, G. M., Skorpanich, M. A, & Evans, G. W. (1982). School environment and stress. In G. W. Evans (Ed.). *Environmental Stress* (pp225-255). Cambridge, MA: Cambridge University Press.

Architectural and Transportation Barriers Compliance Board (1999). Response to petition for rulemaking for classroom acoustics. *Federal Register, 63*(104), 29679-29684.

Berenson, G. (1980). *Cardiovascular Risk Factors in Children.* New York: Oxford University Press

Bistafa, S. R., & Bradley, J. S. (2000). Reverberation time and maximum background-noise level for classrooms from a comparative study of speech intelligibility metrics. *Journal of the Acoustical Society of America, 107*(2), 861-875.

Bolt, R., & MacDonald, A. (1949). Theory of speech masking by reverberation. *Journal of the Acoustical Society of America, 21*, 577-580.

Brady, S., Shankweiler, D., & Mann, V. (1983). Speech perception and memory coding in relation to reading ability. *Journal of Experimental Child Psychology, 35,* 345-347.

Bradley, J. (1986). Speech intelligibility studies in classrooms. *Journal of the Acoustical Society of America, 80*(3), 846-854.

Broadbent, D. E. (1958). Effect of noise on an "intellectual" task. *Journal of the Acoustical Society of America,30*, 824-827.

Broadbent, D. E. (1978). The current state of noise research. Reply to Poulton. *Psychological Bulletin, 95*, 1052-1067.

Broadbent, D. E. (1979). Human performance and noise. In C. M.. Harris (Ed.), *Handbook of noise control.* New York: McGraw-Hill.

Bradley, J. S., Reich, R.D., & Norcross, S. G. (1999). On the combined effects of signal-to-noise ratio and room acoustics on speech intelligibility. *Journal of the Acoustical Society of America, 106*(4), 1820-1828.

Bronkhorst, A.W. (2000). The cocktail party phenomenon: A review of research on speech intelligibility in multiple-talker conditions. *Acustica, 86*(1), 117-128.

Bronzaft, A. L. (1981). The effect of a noise abatement program on reading ability. *Journal of Environmental Psychology, 1*, 215-222.

Bronzaft, A. L, & McCarthy, D. P. (1975). The effect of elevated train noise on reading ability. *Environment and Behavior, 7*(4), 517-527.

Cohen, S., Evans, G.W., Krantz, D. S., Stokols, D. S. (1980). Physiological, motivational, and cognitive effects of aircraft noise on children- Moving from the laboratory to the field. *American Psychologist, 35*(3), 231-243.

Cohen, S., Evans, G.W., Krantz, D. S., Stokols, D. S., & Kelly, S. (1981). Aircraft noise and children: Longitudinal and cross-sectional evidence on adaptation to noise and the effective ness of noise abatement. *Journal of Personality and Social Psychology, 40*(2), 331-345.

Cohen, S., Glass, D., & Singer, J. (1973). Apartment noise, auditory discrimination, and reading ability in children. *Journal of Experimental Social Psychology, 9*, 407-422.

Cohen, S., Glass, D. C., & Phillips, S. (1979). Environment and health. In H. E. Freeman, S. Levine, and L. G. Reeder (Eds.), *Handbook of Medical Sociology*. Englewood Cliffs, N.J.: Prentice-Hall.

Cohen, S., & Lezak, A. (1977). Noise and inattentiveness to social cues. *Environment and Behavior, 9*(4), 559-572.

Cohen, S., & Weinstein, N. (1981). Nonauditory effects of noise on behavior and health. *Journal of Social Issues, 37*, 36-70.

Cooper, J., & Cutts, B. (1971). Speech discrimination in noise. *Journal of Speech and Hearing Research, 14*, 332-337.

Cotterell, J. L. (1984). Effects of school architectural design on student and teacher anxiety. *Environment and Behavior, 16*(4), 455-479.

Crandell, C. (1993). Speech recognition in noise by children with minimal degrees of sensorineural hearing loss. *Ear and Hearing, 14*, 210-216.

Crandell, C. (1996). Effects of sound field FM amplification on the speech perception of ESL children. *Educational Audiology Journal, 4*, 1-5.

Crandell, C., & Bess, F. (1986, October). Speech recognition of children in a "typical" classroom setting. *ASHA, 29*, 87.

Crandell, C., & Smaldino, J. (1996). Speech perception in noise by children for whom English is a second language. *American Journal of Audiology, 5*, 47-51.

Crandell, C., Smaldino, J., & Anderson, K. (2000). Classroom acoustics. *Volta Voices, 7*(4), 28-32.

Crook, M., & Langdon, F. (1974). The effects of aircraft noise in schools around London airport. *Journal of Sound and Vibration, 34*, 221-232.

Dornic, S. & Fernaeus, S. (1982). *Incidental Learning and Processing Rigidity in Noise,* Report No. 589. Sweden: Department of Psychology, University of Stockholm.

Downs, D., & Crum, M. (1978). Processing demands during auditory learning under degraded listening conditions. *Journal of Speech and Hearing Research, 21*, 702-714.

Drullman, R., Festen, J. M., & Plomp, R., (1994). Effect of temporal envelope smearing on speech reception. *Journal of the Acoustical Society of America, 95*(2), 1053-1064.

Edmonds, E. M., & Smith, L. R. (1985). Students performance as a function of sex, noise, and intelligence. *Psychological Reports, 56*(3), 727-730

Elliot, L. (1979). Performance of children aged 9 to 17 years on a test of speech intelligibility in noise using sentence material with controlled word predictability. *Journal of the Acoustical Society of America, 66*(3), 651-653.

Elliott, L., Connors, S., Kille, E., Levin, S., Ball, K., & Katz, D. (1979) Children's understanding of monosyllabic nouns in quiet and in noise. *Journal of the Acoustical Society of America, 66*, 12-21.

Eschenbrenner, A. J. (1971). Effects of intermittent noise on the performance of a complex motor task. *Human Factors, 13*, 59-63.

Evans, G. W., Hygge, S., & Bullinger, M. (1995). Chronic noise and psychological stress. *Psychological Science, 6*, 333-338.

Evans, G. W., & Maxwell, L. (1997). Chronic noise exposure and reading deficits – The mediating effects of language acquisition. *Environment and Behavior, 29*(5), 638-656.

Eysenck, M. W., & Eysenck, M. C. (1979). Memory scanning, introversion-extroversion and levels of processing. *Journal of Research in Personality,13*, 305-313.

Fallon, M., Trehub, S.E., & Schneider, B. A. (2000). Children's perception of speech in multitalker babble. *Journal of the Acoustical Society of America, 108*(6), 3023-3029.

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

Fisher, S. (1972). A "distraction effect" of noise bursts. *Perception, 1*, 223-226.

Gawron, V. J. (1982). Performance effects of noise intensity, psychological set, and task type and complexity. *Human Factors, 24*(2), 225-243.

Gelfand, S. A., & Hochberg, I. (1976). Binaural and monaural speech discrimination under reverberation. *Audiology, 15*, 72-84.

Gelfand, S., & Silman, S. (1979) Effects of small room reverberation upon the recognition of some consonant features. *Journal of the Acoustical Society of America, 66*(1), 22-29.

General Accounting Office Report to Congressional Requesters (1995). *School Facilities: Condition of America's Schools.* GAO/HEHS-95-61. February.

Glass, D. C. & Singer, J. E. (1972). *Urban stress: Experiments on noise and social stressors.* New York: Academic Press.

Gordon-Salant, S. (1985). Phoneme feature perception in noise by normal-hearing and hearing-impaired subjects. *Journal of Speech and Hearing Research, 28*, 87-95.

Graham, F. K. & Slaby, D. A. (1973). Differential heart rate changes to equally intense white noise and tone. *Psycho physiology, 10*, 347-362.

Green, K. B. (1979). *The effects of community noise exposure on the reading and hearing ability of Brooklyn and Queens school children.* Dissertation: New York University.

Green, K., Pasternak, B., & Shore, B. (1982). Effects of aircraft noise on reading ability of school age children. *Archives of Environmental Health, 37*(1), 24-31.

Gump, P. V., & Good, L. R. (1976). Environments operating in open space and traditionally designed schools. *Journal of Architectural Research, 5*(1), 20-27.

Haines, M. M., Stansfeld, S. A., Job, R. F. S., Berglund, B., & Head, J. (2001). Chronic aircraft noise exposure, stress responses, mental health and cognitive performance in school. *Psychological Medicine, 31*(2), 265-277.

Hamilton, P., Hockey, R., & Rejman, M. (1977). The place of the concept of activation in human information processing theory: An integrative approach. In S. Dornic (Ed.), Attention and performance VI. London: Academic Press.

Hartman, G. (1946). The effects of noise on children. *Journal of Educational Psychology, 37*, 149-161.

Helfer, J. S., (1994). Binaural cues and consonant perception in reverberation and noise. *Journal of Speech and Hearing Research, 37*(4), 429-238.

Higgins, A. T., & Turnure, J. E. (1984). Distractibility and concentration of attention in children's development. *Child Development, 55*(5), 1799-1810.

Hiroto, D. (1974). Locus of control and learned helplessness. *Journal of Experimental Psychology, 102*. 187-193.

Hiroto, D., & Seligman, M. E. P. (1975). Generality of learned helplessness in humans. *Journal of Personality and Social Psychology, 31*, 311-327.

Hockey, G. R. J. and Hamilton, P. (1970). Arousal and information selection in short-term memory. *Nature, 226*, 866-867.

Irwin, R. J., & McAuley, S. F. (1987). Relations among temporal acuity, hearing loss, and the perception of speech distorted by noise and reverberation. *Journal of the Acoustical Society of America, 81*, 1557-1565.

Jerison, H. J. (1959). Effects of noise on human performance. *Journal of Applied Psychology, 43*, 96-101.

Johnson, C.E. (2000). Children's phoneme identification in reverberation and noise. *Journal of Speech Language and Hearing Research, 43*(1), 144-157.

Johnson, C. E., Stein, R. L., Broadway, A., & Markwalter, T. S. (1997). "Minimal" high-frequency hearing loss and school age children: Speech recognition in a classroom. *Language Speech and Hearing Services in Schools, 28*(1), 77-85.

Kjellberg, A., & Skoldstrom, B. (1991). Noise annoyance during the performance of different nonauditory tasks. *Perceptual and Motor Skills, 73*(1), 39-49.

Ko, N. (1979). Responses of teachers to aircraft noise. Journal of *Sound and Vibration, 62*, 277-292.

Krantz, D. S., Glass, D. C., & Snyder, M. L. (1974). Helplessness, stress level, and the coronary prone behavior pattern. *Journal of Experimental Social Psychology, 10*, 284-300.

Lochner, J. P., & Burger, J. F. (1961). The intelligibility of speech under reverberant conditions. *Acustica, 11*, 195-200.

Lukas, J. S., DuPree, R. B., Swing, J. W. (1981). *Report of a study on the effects of freeway noise on academic achievement of elementary school children, and a recommendation for a criterion level for a school noise abatement program.* Sacramento, CA: California Department of Health Services.

Maser, A. L., Sorensen, P. H., & Kryter, K. D. (1978) *Effects of intrusive sound on classroom behavior: Data from a successful lawsuit.* Paper presented at the Annual Meeting of the Western Psychological Association, San Francisco.

Mayo, L. H., Florentine, M., & Buus, S. (1997). Age of second-language acquisition and perception of speech in noise. *Journal of Speech Language Hearing Research, 40*, 686-693.

McCroskey, R. & Devens, J. (1975). *Effects of noise upon student performance in public school classrooms.* Proceedings of National Noise and Vibration Control Conference. Chicago, IL.

Moch-Sibony, A. (1984). Study of the effects of noise on personality and certain psychomotor and intellectual aspects of children after a prolonged exposure. *Travail Humane, 47*, 155-165.

Moncur, J. P., & Dirks, D., (1967). Binaural and monaural speech intelligibility in reverberation. *Journal of Speech and Hearing Research, 10*, 186-195.

Nabelek, A. K., & Donahue, A. M. (1984). Perception of consonants in reverberation by native and non-native listeners. *Journal of the Acoustical Society of America, 75*(2), 632-634.

Nabelek, A., & Pickett, J. (1974a). Monaural and binaural speech perception through hearing aids under noise and reverberation with normal and hearing-impaired listeners. *Journal of Speech and Hearing Research, 17*, 724-739.

Nabelek, A., & Pickett, J. (1974b). Reception of consonants in a classroom as affected by monaural and binaural listening, noise, reverberation, and hearing aids. *Journal of the Acoustical Society of America, 56*, 628-639.

Nabelek, A., & Robinson, P. (1982). Monaural and binaural speech perception in reverberation for listeners of various ages. *Journal of the Acoustical Society of America, 71*(5), 1242-1248.

Nelson, P. B. (2000). Improving acoustics in America's schools: Prologue. *Language, Speech, and Hearing Services in Schools, 31*, 354-355.

Neuman, A., & Hochberg, I. (1983). Children's perception of speech in reverberation *Journal of the Acoustical Society of America, 73*(6), 2145-2149.

Nober, L. & Nober, E. (1975). Auditory discrimination of learning disabled children in quiet and classroom noise. *Journal of Learning Disabilities, 8*, 656-677.

Papso, C. F., & Blood, M. (1989). Word recognition skills of children and adults in background noise. *Ear and Hearing, 10*(4), 235-236.

Park, J. F., Jr., & Payne, M. C., Jr. (1963). Effects of noise level and difficulty of task in performing division. *Journal of Applied Psychology, 47*, 367-368.

Passchier-Vermeer, W., & Passchier, W. F. (2000). Noise exposure and public health. *Environmental Health Perspectives, 108*, 123-131.

Patton, J. E., & Offenbach, S. I. (1978). Effects of visual and auditory distractors on learning disabled and normal children's recognition memory performance. *Journal of Educational Psychology, 70*, 788-795.

Percival, L. & Loeb, M. (1980). Influence of noise characteristics on behavioral aftereffects. *Human Factors, 22*, 341-352.

Persinger, M. A., Tiller, S. G., & Koren, S. A. (1999). Back ground sound pressure fluctuations (5 dB) from overhead ventilation systems increase subjective fatigue of university students during three-hour lectures. *Perceptual and Motor Skills, 88*, 451-456.

Plomp, R. (1986). A signal-to-noise ratio model for the speech reception threshold for the hearing impaired. *Journal of Speech and Hearing Research, 29*, 146-154.

Poulton, E. C. (1977). Continuous intense noise masks auditory feedback and inner speech. *Psychological Bulletin, 84*, 977-1001.

Regecova, V. & Kellerova, E. (1995). Effects of urban noise-pollution on blood-pressure and heart-rate in preschool-children. *Journal of Hypertension, 13*(4), 405-412.

Salame, P. & Wittersheim, G. (1978). Selective noise disturbance of the information input in short-term memory. Quarterly *Journal of Experimental Psychology, 30*, 693-704.

Sanz, S. A., Garcia, A. M., & Garcia, A. (1993). Road traffic noise around schools: A risk for pupils performance. *International Archives of Occupational and Environmental Health, 65*(3), 205-207.

Seligman, M. P. (1975). *Helplessness: On Depression, Development, and Death.* San Francisco, CA: Freeman.

Semotan, J., & Semotanova, M. (1969). Startle and other human responses to noise. *Journal of Sound and Vibration, 10*(3), 480-489.

Slater, B. R. (1968). Effects of noise on pupil performance. *Journal of Educational Psychology, 59*, 239-243.

Smith, A. P. (1985). The effects of different types of noise on semantic processing and syntactic reasoning. Acta *Psychologica, 58*, 263-273.

Smith, A. P. (1991). Noise and aspects of attention. *British Journal of Psychology, 82*, 313-324.

Sorkin, D. A. (2001). Classroom acoustics: Understanding barriers to learning (Forward). *The Volta Review, 101*(5), v-ix.

Stelmachowicz, P. G., Hoover, B. M., Lewis, D. E., Kortekaas, R., & Pittman, A. L (2000). The relation between stimulus context, speech audibility, and perception for normal-hearing and hearing-impaired children. *Journal of Speech, Language, and Hearing Research, 43*(4), 902-914.

Stuart, A., Phillips, D. P., & Green, W. B. (1995). Word recognition performance in continuous and interrupted broad-band noise by normal-hearing and simulated hea1ring-impaired listeners. *American Journal of Otology, 16*(5), 658-663.

Stuart, A., & Phillips, D. P. (1997). Word recognition in continuous noise, interrupted noise, and in quiet by normal-hearing listeners at two sensation levels. *Scandinavian Audiology, 26*(2), 112-116.

Teichner, W. H., Arees, E., & Reilly, R. (1963). Noise and human performance, a psychophysiological approach. *Ergonomics, 6*, 83-97.

Theodoridis, G. C., & Schoeny, Z. G. (1988). Comparison of various modes of presenting sentence materials in tests of speech perception in noise. *Journal of the Acoustical Society of America, 84*(5), 2270-2272.

Tinker, M. A. (1925). Intelligence in an intelligence test with an auditory distractor. *American Journal of Psychology, 36*, 467-468.

Towne, R., & Anderson, K. (1997). The changing sound of education. *Sound and Vibration*. January. 48-51.

Webster, J., & Snell, K. (1983). Noise levels and the speech intelligibility of teachers in classrooms. *Journal of the Academy of Rehabilitative Audiology, 16*, 234-255.

Wilding, J. & Mohindra, N. (1983). Noise slows phonological coding and maintenance rehearsal: An explanation for some effects of noise on memory. In G. Rossi (Ed.), *Proceedings of the Fourth International Congress on Noise as a Public Health Problem*, pp. 759-771.. Milan: Centro Richerche e Studi Amplifon.

Wilson, R. H., Zizz, C. A., Shanks, J. E., Causey, G. (1990). Normative data in quiet, broadband noise, and competing message for Northwestern University Auditory Test No. 6 by a female speaker. *Journal of Speech and Hearing Disorders, 55*, 771-778.

Woodhead, M. M. (1964). The effect of bursts of noise on an arithmetic task. *American Journal of Psychology, 77*, 627-633.

Yacullo, W. S., & Hawkins, D.B (1987). Speech recognition in noise and reverberation by school-age children. *Audiology, 26*(4), 235-246.

Zentall, S. S., & Shaw, J. H. (1980). Effects of classroom noise on performance and activity of second-grade hyperactive and control children. *Journal of Educational Psychology, 72*, 830-840.