Speech Intelligibility of Young School-Aged Children in the Presence of Real-Life Classroom Noise

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Abstract

We examined the ability of 40 young children (aged five to eight) to understand speech (monosyllables, spondees, trochees, and trisyllables) when listening in a background of real-life classroom noise. All children had some difficulty understanding speech when the noise was at levels found in many classrooms (i.e., 65 dBA). However, at an intermediate (-6 dBA SNR) level, kindergarten and grade 1 children had much more difficulty than did older children. All children performed well in quiet, with results being comparable to or slightly better than those reported in previous studies, suggesting that the task was age appropriate and well understood. These results suggest that the youngest children in the school system, whose classrooms also tend to be among the noisiest, are the most susceptible to the effects of noise.

Key Words: Classroom noise, signal-to-noise ratio, speech intelligibility

Abbreviations: CID-W-22 = Central Institute for the Deaf Speech Reception Test; dBA = A-weighted decibels; ESP = Early Speech Perception Test for Profoundly Hearing Impaired Children; MLNT = Multisyllabic Lexical Neighborhood Test; MOST = University of Michigan Open-Set Test for Toddlers; SNR = signal-to-noise ratio; WIPI = Word Intelligibility by Picture Identification Test

Sumario

Evaluamos la capacidad de 40 niños (edades de cinco a ocho) para entender el lenguaje (monosílabos, espondaicos, trocaicos y trisílabos) al escucharlo en medio de un auténtico ruido de fondo de aula de clase. Todos los niños tuvieron alguna dificultad para entender el lenguaje cuando el ruido estuvo a los niveles hallados en muchas aulas de clase (p.e., 65 dBA). Sin embargo, a un nivel intermedio (-6 dBA), los niños de jardín de infantes y de primer grado tuvieron más dificultad que los niños mayores. Todos los niños funcionaron bien en silencio, con resultados comparables o hasta ligeramente superiores a los reportados en estudios previos, sugiriendo que la tarea era bien entendida y apropiada para la edad. Estos resultados sugieren que los niños más jóvenes dentro del sistema escolar, cuyas aulas de clase suelen ser las más ruidosas, son los más susceptibles a los efectos del ruido.
The acoustic conditions in the classroom are known to influence children’s academic achievement (Finitzo-Hieber and Tillman, 1978; Nabelek and Nabelek, 1994). Background noise reduces speech intelligibility and may compromise psychoeducational and psychosocial development (Crandell, 1993; Nabelek and Nabelek, 1994). Picard and Bradley (1997) suggested that understanding speech in noise may place the greatest information processing demands on the youngest school-aged children, and noted that this group also creates the most background noise, due to their higher levels of activity.

The degree to which noise interferes with speech depends on a range of factors, including (1) the intensity of the noise relative to that of the speech, (2) fluctuations over time in the noise level relative to the speech, and (3) the spectral characteristics of the signal and of the noise (e.g., Nabelek and Nabelek, 1994). The relative levels of the speech and the background classroom noise can be quantified in terms of the signal to noise ratio (SNR), defined as the intensity level of the speech in relation to the intensity level of the competing background noise. In general, the spectral characteristics and temporal fluctuations of classroom noise are often similar to those of the target speech (i.e., the teacher’s voice).

ACOUSTIC CONDITIONS IN CLASSROOMS

Given that proper acoustics is an essential component to verbal learning, many knowledge-based societies are beginning to implement guidelines and standards for classroom acoustics. The World Health Organization (WHO) has identified the basic acoustical requirements for verbal learning spaces (WHO, 1999). Similarly, Australia, France, Italy, Japan, Sweden, Turkey, the United Kingdom, and the United States have each either completed or proposed national standards for classroom acoustics (Acoustical Society of America, 2000). These standards are being generated in response to a number of studies, which have characterized the noise levels in “typical” classrooms as being too high and have demonstrated, repeatedly, the deleterious effects on classroom performance. Recently, the General Accounting Office in the United States declared 28% of all schools have unsatisfactory levels of noise (General Accounting Office, 1995).

Picard and Bradley (2001) summarized the noise levels of occupied classrooms from a number of different published sources. In general, the studies indicated that the younger the child, the noisier the classroom (Picard and Bradley, 2001). For example, noise levels in an occupied day-care center for four- to five-year-old children were between...
66 and 94 dBA (Picard and Boudreau, 1999), while noise levels in an occupied university classroom were between 44 dBA (Hodgson, 1999) and 55 dBA (Fitzroy and Reid, 1963). A more recent survey in the United Kingdom (Shield et al, 2001) found that average noise levels in their primary classrooms were 72 dBA $L_{Aeq}$. That would be as loud as standing next to a busy intersection.

EFFECTS OF NOISE ON SPEECH INTELLIGIBILITY

Such background noises reduce the intelligibility of speech by masking or distorting acoustic cues in the speech signal. For example, Houtgast (1981) determined that 42 dBA external traffic noise reduced the intelligibility of monosyllabic words in the classroom to below 50% correct when the SNR reached -15 dBA (the teacher’s long-term speech level was 57 dBA).

In general, normal-hearing children tend to have more difficulty understanding speech in the presence of background noise than do normal-hearing adults (Picard and Bradley, 2001). For example, Nittrouer and Boothroyd (1990) reported that kindergarten children had lower recognition scores than young adults for words, nonsense words, and four-word monosyllabic sentences presented at 65 dB SPL in a background of speech-shaped noise at +3, 0, and -3 dB SNR. Elliot et al (1979) reported that children’s comprehension of monosyllabic nouns in noise reached normal adult level by age 10. Elliot et al (1979) also found that children aged 5 to 7 years required a 5 dB higher SNR to achieve a 71% level of accuracy in identifying monosyllables than did those aged 10 years or older. Moreover, these researchers reported that 9- to 13-year-old normal-hearing children performed less well at each of +5, 0, and -5 dB SNRs than did 17 year olds.

These results suggest that listening in classroom noise will reduce speech comprehension for children, possibly to a significant extent. However, the magnitude of this effect under “typical” classroom conditions remains unclear. Many of the previous studies have used adult multitalker babble as background noise, not noise that is representative of the background noise a child is exposed to in the classroom (i.e., voices of other children, furniture noise, ventilation, and other equipment noise). The objective of the present study was to provide such data for the youngest school-aged children, who are expected to be the most susceptible to the effects of noise.

A COMPUTER-BASED PEDIATRIC TEST OF SPEECH INTELLIGIBILITY FOR FAMILIAR WORDS

A number of speech tests for young children have been developed to assess the speech perception and/or production abilities of young children. Existing formal tests include the Early Speech Perception Test for Profoundly Hearing Impaired Children (ESP; Moog and Geers, 1990), the Word Intelligibility by Picture Identification Test (WIPI; Ross and Lerman, 1970), the CID-W-22 Speech Reception Test (Hirsh et al, 1952), the University of Michigan Open-Set Test for Toddlers (MOST; Zwolan et al, 1997), and the Multisyllabic Lexical Neighborhood Test (MLNT; Kirk et al, 1995).

Unfortunately, a number of problems have been identified with existing tests: (1) in a number of cases, word lists have become outdated so that certain words used in the test are no longer within the vocabulary of most young children; (2) many word lists are not recorded so that live-voice presentation is necessary; (3) those recordings that are available are often of poor sound quality, and they frequently involve a single adult male talker, so results may generalize incompletely to performance in the kindergarten/primary classroom where many teachers are female; (4) with the exception of Moog and Geers (1990), no widely available test includes monosyllables, spondees, trochees, and trisyllables to permit the assessment of performance differences across word structure; and (5) the lists have not been integrated with a standardized computer based testing protocol.

In view of the above concerns, items in existing standardized tests were examined to generate a revised list containing items that were: (1) within the current vocabulary of most young children in North America and (2) able to be represented pictorially so that the items could be used in a computer-based test with young preschool and school-aged children. The list included differences in syllabification, reflecting the variety of words in the vocabulary of young children, so that the effects of noise on various types of word
structures could be measured.

Studies of children's speech perception in noise have often required the child to make a verbal or written response. Use of an oral response permits ambiguity as young children frequently display poor articulation, so their response may be unintelligible and/or the examiner may mishear the response and score the child's response inaccurately (Ross and Lerman, 1970). Written responses introduce legibility and literacy issues and may delay testing and differentially tax the ability of young children to complete the study. An alternative, pointing to clearly defined pictures of words, helps to avoid interpretation errors and speeds testing. This study, therefore, used this type of response.

The purposes of the present study were to: (1) measure the abilities of young children to understand speech heard against classroom noise at different levels, (2) examine how identification accuracy varied for children of different ages, and (3) determine whether word structure affects such speech comprehension.

**METHOD**

**Subjects**

Forty kindergarten and elementary students participated in the study. Ten children were selected from each of kindergarten (aged five), grade 1 (aged six), grade 2 (aged seven), and grade 3 (aged eight). All participants were native speakers of English. Hearing thresholds were measured bilaterally at 500, 1000, 2000, and 4000 Hz, using supra-aural headphones. Inclusion criteria were: (1) normal appearance of the ear canal and tympanic membrane; (2) pure-tone air-conduction thresholds no worse than 15 dB HL at 1000, 2000, and 4000 Hz in either ear; (3) acoustic immittance measures for static compliance between 0.3 and 1.6 ml; and (4) middle ear pressure between 50 and -150 daPa bilaterally.

**Speech Stimuli**

Sixty words (24 monosyllables, 12 spondees, 12 trochees, 12 trisyllables) chosen to be within the vocabulary of young children and able to be represented pictorially were used. All words were spoken by an adult female talker. The words were sampled as .wav files at 22.5 kHz using the Time Frequency Response (TFR) software (Avaaz Innovations Inc., 1997a) and processed to equalize the RMS value of the vowels for syllables in the monosyllabic, spondee, and trisyllabic words. The RMS of the entire syllable was adjusted to achieve 1.75 mV RMS for a 100 msec window centered on the peak of the vowel. The secondary syllable in the trochees was edited to have an RMS value equalling approximately 0.88 mV for a 100 msec sample of the vowel (i.e., half the RMS of the primary syllable), facilitating the distinction of spondees from trochees (airplane vs. baby). The RMS value of individual consonants was adjusted as required to ensure that each item sounded natural.

Classroom noise was obtained using a DAT recorder connected to a Shure SM81 two-inch condenser microphone placed centrally in a grade 5 classroom, occupied by 26 students and one teacher. The ambient background noise at the back of the room, measured using a Brüel and Kjær Sound Level Meter with a B&K Type 4165 Condenser Microphone, varied between 60 dBA and 70 dBA. A representative sample of this classroom noise was edited for use in the test.

Each word was mixed digitally with the sample of classroom noise at different signal-to-noise ratios (SNR) to create four conditions: Quiet (original sample), 0 dB, -6 dB, and -12 dB. After scaling, the signal and noise were mixed, and the RMS value of the mixed signal was then equalized to the RMS value of the original signal. Noise was also appended to this composite file, providing a 200 msec buffer of classroom noise at the beginning and end of the composite signal.

**Procedure**

All aspects of the experiment were controlled by a PC computer, running the ECoS experiment control software (Avaaz Innovations Inc., 1997b). All test signals and noise were replayed over the computer's 16-bit Creative Laboratories' Sound Blaster 16 sound card, and presented bilaterally over Telephonics TDH 49 supra-aural headphones. Words were played at 65 dB SPL over the headphones to simulate the vocal intensity normally used by teachers in the classroom,
speaking at a distance of one meter. The headphones were calibrated with a 1000 Hz pure tone with an RMS value of 1.75 mV in a 6 cc coupler, as measured with a Quest 155 sound level meter.

Subjects were tested individually in a classroom (ambient background noise at the test location varied between 54.9 and 59.3 dBC), while seated in front of a computer monitor used to display the 12 response choices for each trial. Each listener was required to point to one of the 12 pictures on the monitor that best represented the word presented over the headphones (see Figure 1).

At the start of a trial, a dialog box appeared on the screen saying: “Ready? Listen carefully.” The minimum intertrial interval was fixed at 200 msec, but a word was presented only after the experimenter judged that the child was attending to the task. Each test consisted of five blocks: monosyllables—front to mid vowels; monosyllables—mid to back vowels; spondees; trochees; and trisyllables. The signals within each block were presented randomly without replacement. Additionally, the sequencing of the blocks was randomized to control for order effects.

Kindergarten and grade 1 listeners
received a short training block prior to testing to ensure that they were able to associate each word stimulus with the appropriate pictorial response. The training block allowed the experimenter to confirm that each child appeared to understand, and was able to perform, the task.

Kindergarten and grade 1 subjects participated in two sessions of 15 minutes each, on a single day—one in the morning and one in the afternoon. Grade 2 and 3 children participated for one 30-minute session.

**RESULTS**

For each set of word stimuli and SNR condition, each listener’s responses were cumulated, and the mean number of correct responses (out of 12 trials) was calculated. Table 1 displays mean word-recognition scores (percent correct), averaged across listeners, within each grade level, as a function of the SNR and type of word stimulus.

It can be seen that, as expected, performance in quiet was very good for children at all grade levels, for all types of items. This result confirms that the words used were age appropriate, even for the youngest subjects, and that all children understood and were capable of performing the task.

As SNR decreased, performance declined. For example, in quiet, kindergarten subjects identified an average of 97% of monosyllable mid-front (M-F) vowel words. However, in background noise at -12 dB SNR they identified just 72% of these words correctly. On average, grade 3 subjects correctly identified 99.2% of M-F words in quiet, but just 80% at the -12 dB SNR.

In general, accuracy was highest overall for trisyllables (M = 98%), followed by spondees (M = 96%), monosyllable mid-back (M-B) vowels (M = 93%), trochees (M = 91%), and monosyllable mid-front vowels (M = 88%). Overall, scores decreased as the SNR decreased from quiet (M = 98%) to 0 dB (M = 97%), -6 dB (M = 94%), and -12 dB (M = 84.7%). Identification accuracy increased with grade level, with grade 3 children having the highest overall score (M = 95%), followed by grade 2 (M = 94%), grade 1 (M = 93%), and kindergarten (90%) children.

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**Table 1. Means and SDs by Grade Level, as a Function of Signal-to-Noise Ratio and Type of Word Stimulus**

<table>
<thead>
<tr>
<th>Grade</th>
<th>Stimuli</th>
<th>Quiet M (SD)</th>
<th>0 dB SNR M (SD)</th>
<th>-6 dB SNR M (SD)</th>
<th>-12 dB SNR M (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>Kindergarten</td>
<td>Monosyllables (M-F)</td>
<td>97.5 (4)</td>
<td>90.0 (8.6)</td>
<td>73.6 (18.4)</td>
<td>71.7 (18.1)</td>
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<tr>
<td></td>
<td>Monosyllables (M-B)</td>
<td>94.2 (6.9)</td>
<td>98.3 (3.5)</td>
<td>86.7 (16.3)</td>
<td>80.0 (17.2)</td>
</tr>
<tr>
<td></td>
<td>Spondees</td>
<td>98.3 (3.5)</td>
<td>95.8 (5.9)</td>
<td>90.0 (11.7)</td>
<td>89.2 (7.9)</td>
</tr>
<tr>
<td></td>
<td>Trochees</td>
<td>93.3 (7.7)</td>
<td>95.0 (9)</td>
<td>91.7 (9.6)</td>
<td>73.3 (23.2)</td>
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<tr>
<td></td>
<td>Trisyllables</td>
<td>98.3 (3.5)</td>
<td>100.0</td>
<td>100.0</td>
<td>81.7 (18.3)</td>
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<tr>
<td>Grade 1</td>
<td>Monosyllables (M-F)</td>
<td>94.2 (6.9)</td>
<td>94.2 (4)</td>
<td>76.4 (13.7)</td>
<td>75.8 (10.7)</td>
</tr>
<tr>
<td></td>
<td>Monosyllables (M-B)</td>
<td>97.5 (4)</td>
<td>97.5 (4)</td>
<td>92.5 (8.3)</td>
<td>86.7 (11.2)</td>
</tr>
<tr>
<td></td>
<td>Spondees</td>
<td>98.3 (5.3)</td>
<td>97.5 (5.6)</td>
<td>95.0 (5.8)</td>
<td>92.5 (7.3)</td>
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<tr>
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<td>Trochees</td>
<td>90.8 (9.2)</td>
<td>97.5 (5.6)</td>
<td>93.3 (6.6)</td>
<td>84.2 (10)</td>
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<td></td>
<td>Trisyllables</td>
<td>99.2 (2.6)</td>
<td>100.0</td>
<td>99.2 (2.6)</td>
<td>98.3 (3.5)</td>
</tr>
<tr>
<td>Grade 2</td>
<td>Monosyllables (M-F)</td>
<td>96.7 (4.3)</td>
<td>92.5 (7.3)</td>
<td>97.3 (4.4)</td>
<td>77.5 (12.5)</td>
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<tr>
<td></td>
<td>Monosyllables (M-B)</td>
<td>97.5 (4)</td>
<td>100.0</td>
<td>94.2 (6.9)</td>
<td>77.5 (15.3)</td>
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<tr>
<td></td>
<td>Spondees</td>
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<td>97.1 (5.6)</td>
<td>95.8 (5.9)</td>
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<tr>
<td></td>
<td>Trochees</td>
<td>100.0</td>
<td>98.3 (5.8)</td>
<td>98.3 (3.5)</td>
<td>75.8 (13.5)</td>
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<tr>
<td></td>
<td>Trisyllables</td>
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<td>100.0</td>
<td>99.2 (2.6)</td>
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<tr>
<td>Grade 3</td>
<td>Monosyllables (M-F)</td>
<td>99.2 (2.6)</td>
<td>94.2 (5.6)</td>
<td>94.5 (6.4)</td>
<td>80.0 (14.3)</td>
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<td></td>
<td>Monosyllables (M-B)</td>
<td>98.3 (3.5)</td>
<td>99.2 (2.6)</td>
<td>95.0 (5.8)</td>
<td>91.7 (10.4)</td>
</tr>
<tr>
<td></td>
<td>Spondees</td>
<td>99.2 (2.6)</td>
<td>95.8 (9.1)</td>
<td>99.2 (2.6)</td>
<td>95.0 (5.8)</td>
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<td></td>
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<tr>
<td></td>
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<td>98.3 (3.5)</td>
<td>99.7 (4.3)</td>
<td>95.0 (10.5)</td>
</tr>
</tbody>
</table>
Interactions

A MANOVA was performed on the data with SNR condition (four levels) and type of stimulus (five levels) as within-subjects factors and grade level (four levels) as a between-subjects factor. The three way interaction of grade by SNR by type of word stimulus was significant (F(432, 18.17) = 2.28, p < .05).

Subsequently, two separate sets of MANOVAs were conducted to allow these differences to be examined in greater detail. The first set of MANOVAs examined SNR (four levels) and grade level (four levels) for each type of stimulus. These MANOVAs confirmed that there were significant differences among these 16 means for M-F words, (F(108, 6.88) = 3.62, p < .05) and for trisyllables (F(108, 3.76) = 4.35, p < .05). Post hoc comparisons were performed using the Tukey (1977) Honestly Significant Difference (HSD) test to determine which of these means differed significantly from each other.

The second set of MANOVAs examined the influence of the type of word stimulus used in the test (five levels) for children at the different grade levels (four levels), for each of the four SNR conditions. The MANOVA confirmed that there was a significant difference among the 20 overall means tested in the quiet (F(144, 9.03) = 2.31, p < .05) and -6 dB SNR conditions (F(144, 8.30) = 4.10, p < .05). Performance did not differ in the 0 dB and -12 dB SNR conditions. Post hoc comparisons were performed using Tukey’s (1977) HSD test to determine which of these means differed significantly from each other.

Examination of Significant Interactions

A particularly important interaction, evident in Figure 2, involves the monosyllable M-F vowel stimuli. In quiet and at 0 dB, all children performed at an approximately comparable level in the M-F condition. However, at -6 dB SNR, the scores for kindergarten and grade 1 children declined precipitously, while those for grades 2 and 3 children remained high until they encountered the very unfavorable -12 dB condition (see Figure 2). This significant difference in scores suggests that while older (grade 2 and 3) children can tolerate intermediate (-6 dB SNR) levels of noise, younger (kindergarten and grade 1) children cannot.

Figure 3, which displays performance across the five types of word conditions, when the signal-to-noise ratio was -6 dB SNR, provides further and more general evidence

Figure 2. Mean percent correct word identification for monosyllable mid-front vowel stimuli at each SNR condition for each group of listeners. (Symbols as for Figure 3.)
that grade 2 and 3 children could tolerate this unfavorable noise condition, but that kindergarten and grade 1 children could not. The performance of children in grades 2 and 3 was relatively flat across the various types of word stimuli, while kindergarten and grade 1 children showed a clear improvement in performance from monosyllabic through to trisyllabic words. Kindergarten subjects performed worst, and grade 1 children only somewhat better for each of the M-F, M-B, spondee, and trochee words, respectively. Only with the trisyllables did these differences between grade levels disappear.

**DISCUSSION**

The classroom noise sampled in this study ranged from 60 dBA to 70 dBA during the recording session. These classroom noise levels would create SNRs between +5 dB and -5 dB, for a student one meter away from a teacher speaking at an average level (65 dBA). The SNR would be less favorable further away from the teacher. In particular, SNR would be much less favorable near the back of the classroom, because the teacher’s voice loses intensity with increased distance from the source.

In general, performance in the present study was comparable to or better than that observed under similar SNR conditions in previous studies of children’s speech perception (see Picard and Bradley, 2001). Computer-based testing with pictures reduces response errors due to ambiguous verbal or written responses and may have increased the quality of the data. Moreover, since performance in the more difficult listening conditions of the present study was, in general, better than those predicted on the basis of previous studies, we conclude that the methods and word lists used here are more appropriate for use with younger children than those used in some previous studies.

As expected, we found that speech intelligibility declined as the signal-to-noise ratio decreased. Also, performance differed as a function of SNR condition, word stimuli, and grade level. The result of greatest interest is the finding that younger children are much less able to understand speech in intermediate levels of classroom noise. Kindergarten and grade 1 children were especially affected by noise in the -6 dB SNR, and this effect was particularly clear for monosyllable mid-front vowel words. Again, this finding is alarming given that these younger children tend to also be the noisiest (Picard and Bradley, 1997).
Studies of classroom acoustics demonstrate that a -6 dB SNR in the classroom is quite common (see Picard and Bradley, 2001). Classroom noise both masks the target speech and may also interact with the speech to create the percept of a phoneme that was not present in the target stimuli (e.g., confusing bear for hair). When such errors occur with key words, younger children can easily lose the content of the message due to their inability to take advantage of language context effects (Jerger et al., 1995). Subsequently, academic achievement suffers.

The present study examined speech perception in noise with the stimuli presented at a level equivalent to the teacher standing one meter away from the listener. These results are therefore likely to underestimate the effects of classroom noise on speech perception for children at greater speaker-to-listener distances, such as those at the back of a classroom. Crandell and Smallino (1995) reported that under typical classroom conditions in +6 dB SNR multitalker babble, mean monosyllabic recognition scores decreased from 90% at 6 feet to 35% at 24 feet. These results suggest children in the back of the classroom are at a much greater risk of failing to hear the teacher’s speech.

This research is part of a growing body of evidence that “typical” classroom noise levels have significant, negative effects on the performance of young children. This study further demonstrates that this is particularly true for the youngest, school-aged children. Perhaps the evidence for degraded speech perception in the presence of excessive classroom noise will be useful in continuing to persuade legislators and educators of the need for improved acoustic conditions for classrooms. These actions would (1) reduce noise levels in classrooms through reductions in ventilation and other noise sources; (2) enact and apply construction specifications to better control sound transmission and reverberation; and (3) increase the availability of sound-field FM amplification systems to improve signal-to-noise ratio throughout the classroom environment, for all students.

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