The Effect-of Classroom Amplification on the Signal-to-Noise Ratio in Classrooms While Class Is in Session

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The Effect of Classroom Amplification on the Signal-to-Noise Ratio in Classrooms While Class Is in Session

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Many schools have attempted to ameliorate the negative effects of background noise and reverberation in classrooms by installing classroom amplification systems (also referred to as sound-field amplification systems). Classroom amplification systems are similar to self-contained, high-fidelity, wireless public address systems. Each system generally consists of a microphone worn by the teacher that is attached to a transmitter that encodes the signal from the microphone as either an infrared or frequency modulation (FM) signal. The signal is then transmitted to a receiver, which relays the signal to loudspeakers that amplify the signal. These loudspeakers may be portable or permanently installed in the classroom (Crandell, Smaldino, & Flexer, 1995). The purpose of a classroom amplification system is to amplify a teacher's voice in the classroom setting and create a favorable signal-to-noise ratio (SNR), meaning that the teacher's voice is more intense than the competing background noise in the classroom.

ABSTRACT: **Purpose:** The purpose of this study was to measure the signal-to-noise ratios in classrooms while class was in session and students were interacting with the teacher and each other.
Method: Measurements of noise and reverberation were collected for 5 different classrooms in 3 different schools while class was in session. Activities taking place during the measurements were recorded to compare with sound level measures. The use of infrared classroom amplification was compared with no amplification.
Results/Conclusion: The results revealed that when classroom amplification was used, students heard the teacher's voice at a level that was an average of 13 dB above the noise floor as compared to an average of +2 dB above the noise floor without amplification.

KEY WORDS: classroom acoustics, classroom FM system, signal-to-noise ratio

Typically, classroom amplification systems are reported to improve the SNR by approximately 8–10 dB (Crandell, Smaldino, & Flexer, 1997). Several studies have demonstrated that the speech recognition performance of children is improved when classroom amplification is present in a classroom. Benefits have been demonstrated for children with normal hearing (Crandell, 1996; Eriks-Brophy & Ayukawa, 2000), children for whom English is a second language (Crandell, 1996), children with developmental disabilities (Flexer, Millin, & Brown, 1990) such as Down syndrome (Bennetts & Flynn, 2002), and children with mild hearing loss (Neuss, Blair, & Viehweg, 1991). These benefits provide strong support for the use of classroom amplification not only for children with hearing loss, but also for elementary schoolchildren in general.

Although most reports have been positive, some authors have raised concerns that classroom amplification may not be effective in all situations where the acoustics of a classroom are poor. Two authors have raised the question of whether classroom amplification is effective in the presence of high levels of reverberation (Boothroyd, 2004; Lubman, 2005). One study showed that first-grade students in classrooms with an amplification system, while initially demonstrating benefit from the system, did not demonstrate superior speech recognition over students in classrooms without amplification after using the amplification system for 2 years (Mendel, Roberts, & Walton, 2003). More research concerning classroom amplification is needed to understand its limitations and strengths so that it can be used appropriately for the benefit of students.

A question about classroom amplification that has not received significant attention in the literature is whether all students across the classroom receive similar benefits from the increased SNR that is provided by the system (Crandell et al., 1997). The placement of the loudspeakers, their directivity pattern, the acoustics of the

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room, and the volume level setting of the system all contribute to the distribution of sound in a room. For unamplified speech, research has demonstrated that the quality of the speech signal that is received at various locations in a classroom varies (Leavitt & Flexer, 1991). It is unknown whether each child in a classroom with a classroom amplification system receives a significant boost to the SNR at his or her position in the classroom. Previous research has only reported changes in the mean speech recognition performance of listeners when describing the benefits of classroom amplification (e.g., Crandell, 1996; Jones, Berg, & Viehweg, 1989; Neuss et al., 1991) rather than reporting benefit at different positions within a classroom.

An equally important question concerns student communication in a classroom. Classroom amplification systems are classically designed to amplify the teacher's voice and not those of students. However, several commercially available classroom amplification systems have the option of using a microphone that students can pass among themselves so that student comments are also amplified. Markides (1986) reported that when noise levels in a classroom were high, teachers adjusted the intensity of their speech so that they could be heard over the noise, but students did not make similar adjustments. Investigation of the use of microphones by students is needed to demonstrate whether microphone use provides adequate improvement in the SNR of students' voices so as to render the student communication accessible to other children in the classroom.

Because it is well-established that improving the SNR of speech corresponds to improved speech recognition (Elliott, 1979; Finitzo-Heiber & Tillman, 1978), if one can demonstrate that the SNR at various positions in the classroom is favorable with classroom amplification, it can be reasonably assumed that speech recognition will be improved for most children. In a search of available literature, no studies were found that demonstrate the SNR benefit of classroom amplification systems at various positions in a classroom. This is likely due to the fact that it is difficult to estimate the actual SNR when class is in session because measurements with a sound level meter or other device measure overall sound level and cannot distinguish between the teacher's voice and those of students talking during class or other noises in a classroom. Therefore, the literature was searched again to determine the best way to estimate the SNR in a classroom.

Estimating the SNR of Speech in a Classroom

Only a handful of researchers have made measurements while class is in session to describe the actual acoustic conditions that listeners face while learning (Barton, 1989; Hodgson, Rempel, & Kennedy, 1999; Houtgast, 1981; Markides, 1986; Sato & Bradley, 2004). Of these researchers, Houtgast, Markides, Hodgson et al., and Sato and Bradley have attempted to estimate the SNR of the teacher's speech to the competing noise sources in the classroom. A few different approaches for estimating the SNR in the room were identified among these four studies.

Houtgast (1981) measured the intensity levels of speech produced by teachers as they read lists of monosyllabic words embedded in a carrier phrase to students. The students chose the word they thought the teacher spoke from a list of four words. This same procedure was carried out in a quiet room without significant reverberation, in quiet classrooms with reverberation (though reverberation times were not reported), and in classrooms that were chosen for their high levels of noise from road traffic. In the high-noise classrooms, the test was carried out both with the windows of the classrooms open and with them closed. Measurements were made with a microphone and tape recorder, and the peak levels were considered to represent the teachers producing the monosyllabic words. The period just following each word was used as a measure of the ambient noise in the room. From these measures, Houtgast estimated SNRs for the classrooms of between –0.9 dB and 14.4 dB.

The method that Houtgast (1981) used to estimate the SNR had the advantage of being repeatable and less variable than other approaches that simply measure the speech of teachers in class because each teacher spoke the same words from the list of words. However, there is the risk that the teachers did not use the same intensity they would have if they had simply been teaching their students rather than being recorded reading a list. Also, the measures were made in only one position in the room, and all speech recognition scores were averaged. No data were reported regarding the performance of children at different positions within any of the rooms.

Markides (1986) measured the intensity of teachers' voices with a sound level meter in dBA and reported the "most commonly occurring value" (p. 116) on the sound level meter. These measures were made in 12 classrooms for children with hearing loss while class was in session. Measurements of a teacher speaking were made 2 m from the position of the teacher in each classroom. Measures of student intensity were made by noting the most commonly occurring level of a student's speech, as measured 2 m from the student, when the student was either responding to a question or making a comment. Markides reported the average level of the teachers' voices to be 57.5 dBA and that of the students to be 52.9 dBA. Three values for the background noise in the classrooms were reported, including one measure of loud, transient noises such as the closing of a drawer (determined as the most intense sound level meter reading occurring in a 5-min period and reported as 76.25 dBA in this study); longer nonstationary noise from the activity and "chatter" of the children in the classroom (measured with the "most commonly occurring" method and reported as 61 dBA); and long-term stationary noise from the ventilation system of the classroom and other traffic noise from outside of the classroom ("most commonly occurring" method again, 46.5 dBA). From these measures, the SNR of the teacher's voice in the classroom was determined to be –16.75 dB for transient noises, –4.5 dB for the noise from the students in the room, and 11 dB for the outside noises.

Generalization of the results reported by Markides (1986) to other classrooms is problematic for a few reasons. Because Markides carried out his study in classrooms for children with hearing loss, the number of students in each classroom was small (6 students on average). Also, as was the case with the data from Houtgast (1981), the transmission of speech across a classroom differs significantly at different positions in a room (Leavitt & Flexer, 1991), but the data from Markides came only from one position in the room, 2 m from the teacher. An average that is based on data from multiple sources in the classroom might provide a more accurate estimate of the average SNR that was experienced by the majority of students in the classroom, especially for larger classrooms or those with larger numbers of students.

Another approach to estimating the SNR in a classroom was developed by Hodgson et al. (1999). These authors made recordings in 11 college classrooms of lectures at three or four positions in each classroom. To estimate the levels of the voice of the professor lecturing, the noise coming from students in the classroom, and the level of the ambient noise caused by the ventilation system and noises from outside of the classroom, the authors examined the frequency distribution (in the statistical sense and not the acoustic sense) of the sound levels recorded in each room. The authors observed that the most intense parts of the frequency distribution corresponded to when the professor was lecturing, a less intense distribution corresponded to the noise made by students in the room, and an even less intense distribution corresponded to the ambient noise from within and outside of the room. The results of the analyses of these three distributions of sound energy in the classrooms showed that noise from the ventilation system averaged 40.8 dBA across classrooms, student activity noise was on average 41.9 dBA, and the resulting total average background noise level was 44.4 dBA. The speech of the instructor was estimated at an average level of 50.8 dBA, and the average SNR across the classrooms was 7.9 dBA.

This statistical approach using the frequency distribution of intensities was also used by Sato and Bradley (2004) in elementary school classrooms in Canada. Only the intensity of the teachers' speech and the noise from the students were estimated in this study. Measurements were made using four sound level meters at four locations within each of 28 rectangular-shaped classrooms. Sato and Bradley reported the mean SNR of the intensity of the teachers' voices to the student noise in the classrooms to be 11 dB.

The method used by Hodgson et al. (1999) and by Sato and Bradley (2004) of examining frequency distributions of the intensity of recordings made in a room is an attractive method due to its repeatability and the face validity of being able to record the teacher's speech during lectures or instruction periods with instrumentation that can be set up and then left in the room. Research would be needed to confirm this idea, but it may be that this method could be less intimidating for a teacher and may lead to more natural speech levels during measurements. Also, Hodgson et al.'s method used measurements in various locations in the classroom to account for the variability of speech intensity that may exist across a classroom. One difficulty with this method is that without some observation during the measurement, there is no means of verifying that all or the majority of the intensity levels recorded and included in a particular distribution actually were produced by one entity or another. For example, if the SNR was close to 0, it may be particularly difficult to determine, without some observation during the measurement, whether a teacher produced a particular set of intensity levels or whether it was the children in the classroom.

Estimating the SNR in a classroom is important for several reasons. Knowing the SNR can help determine the most appropriate kind of amplification that children need in learning environments. Also, knowing how acoustic conditions differ across a classroom can help with decisions of student placement in a classroom. Information about the acoustic challenges that children face in a classroom can motivate adapting auditory training and teaching coping strategies to children in particularly poor acoustic environments. Ultimately, knowledge of actual classroom conditions can lead to a better understanding of student performance in classrooms and the effectiveness of solutions that are used to overcome poor classroom acoustics or excessive ambient noise.

It was determined from reviewing these four studies that useful information could be gained from making measures of sound levels and student activity in elementary school classrooms at various positions in each classroom. None of the four previous studies measured classroom SNR values when a classroom amplification system was in place. A direct observation approach was chosen over the approach of Hodgson et al. (1999) and Sato and Bradley (2004) to use frequency distribution data because it was felt that observations of the activities occurring during the measurements would provide better specification of the source of the sound intensities in the classroom. In the direct observation approach used in the present study, equipment to measure the intensity of sound in the classroom was employed, and an observer was present in the classroom to record the source of the sounds that were made during the measurements. When the teacher or a particular child was speaking to the class, peak intensity levels were used to calculate the levels of the speech. Also, ongoing speech from multiple talkers, student-generated noise, and other ambient noise were identified by the observer. The peaks of the intensity measurements that occurred during these periods (identified by the observer in the room) were used to estimate the intensity of this student-generated noise. Finally, the low points or "valleys" of intensity in the measurements were identified as periods where there was no teacher or child speech. In these cases, the intensity of sound in the room dropped to levels that approximated the unoccupied noise floor levels. From these measurements, four categories of sound intensities were classified by the observer in the classroom, namely, teacher speech, child speech, child group noise, and the occupied noise floor.

The ability of the observer to classify the intensities recorded in the classroom and to note the sources involved in a particular intensity measurement is the primary advantage of the direct observation method over other methods, like that used by Hodgson et al. (1999). However, each intensity measure contains a mix of ambient noise and noise that is generated by people in the classroom, including child and teacher speech, whose individual intensity contributions to the overall intensity measurement cannot be reliably separated. Though the intuitive idea of the authors was that the direct observation method would be better at specifying the source of sound intensities in the classroom, it must be pointed out that there is no research to support this idea. Houtgast (1981) used the average intensity of the peaks of the recorded speech in his study to characterize the level of a teacher's voice. This same method was chosen to estimate the level of the teachers' speech and the speech of the children in the present study as it was deemed a reliable and repeatable method of characterizing the intensity of the speakers in the classroom.

Based on our review of previous research estimating the SNR occurring in occupied classrooms, measurements to estimate the SNR in classrooms both with the use of a classroom amplification system and without it were undertaken to achieve three main purposes:

- Obtain SNR data from occupied classrooms based on measurements at nine positions in the classroom to account for variability in levels across the classroom.
- Compare the SNR of teachers' voices in their classrooms with and without the use of a classroom amplification system.
- Obtain SNR data for student speech in the classroom without amplification and also with the use of a handheld microphone that amplified the student speech through the classroom amplification system.

Meeting these three purposes provided valuable information about the SNR across the classroom, enabling evaluation of the performance of the classroom amplification system at various points in the room. Also, the SNR benefits of a classroom amplification system for student communication were able to be observed and quantified.

METHOD

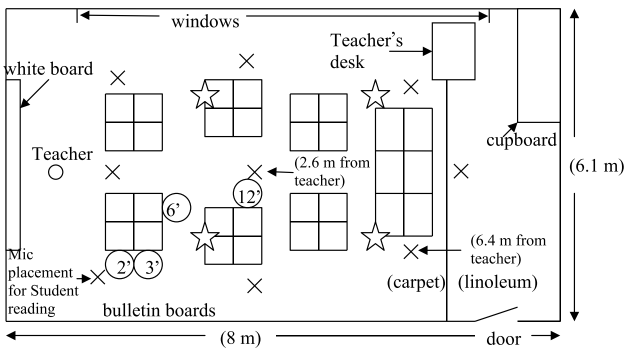
Classroom Selection

Four classrooms, located in either the central or northern parts of the state of Utah, were selected for the study. The 4 classrooms were similar in size, being rectangular in shape, with widths ranging between 8–10 m and depths between 6–8 m. Each classroom met the American National Standards Institute (ANSI) requirements (ANSI S12.60-2002) for reverberation time and ambient noise levels measured with the classroom empty. Once children and the teacher were added to the room, the noise levels in each of the classrooms were radically different.

The 4 classrooms were selected from available fourth-grade classrooms in the regular education curriculum only. This choice was made not because of anything particular about fourth-grade classrooms, but rather so that when the classrooms were compared, there would be more control over the variability of making measures in classrooms of students of different grades (for a discussion of noise levels changing with grade level, see Picard & Bradley, 2001). Also, in order to avoid choosing an extremely poor acoustic classroom that might skew the data in an overly negative manner, only classrooms that were housed in buildings that were built within the last 10 years were selected. The number of students in each classroom was highly similar, with a range of 24 to 26 students per classroom. Figure 1 shows a drawing of 1 of the classrooms that is representative of the rectangular shape and arrangement of the desks in each of the 4 classrooms.

Each classroom was equipped with an Audio Enhancement Ultimate 2000 dual channel infrared system. All loudspeakers (four 4-in. cone speakers with 35-watt RMS capability and a ±3 dB frequency response from 80 Hz to 12 KHz) were ceiling mounted and were placed in different quadrants of the room so as to provide dispersed sound throughout the room. Building principals were contacted and permission was sought to complete measurements in the classrooms.

Figure 1. Example of 1 of 4 classrooms where measures were made for the present study. X represents positions where 10-min measurements of sound pressure level in dBA were made with the TEF system. Stars represent the locations of the ceiling-mounted loudspeakers in the room. The microphone placement in the front-left side of the classroom was used to measure the intensity of students as they read aloud. The circles show the location of the students who spoke with the distances from the microphone shown.



Equipment

A time, energy, frequency (TEF) system (Techron TEF System-20) coupled to a Macintosh laptop was used to obtain measurements of noise and reverberation in each classroom. For measurements of the acoustic properties of the unoccupied classrooms, the TEF system was coupled to the classroom amplification system loudspeakers and measurements were made 1 m directly below the front-left loudspeaker in each classroom with the use of a Radio Shack omnidirectional microphone (Model 33-3036) plugged into the TEF system's processing unit. The TEF System-20 generates a 20-s broadband signal to be played through the loudspeaker and synchronizes the measurement in time through the microphone with the onset of the signal presented from the loudspeaker. The measured 20-s signal is evaluated for its intensity (energy) and frequency spectrum over time. With the measurement of energy and frequency over time, the TEF system can then calculate, in addition to other acoustic indices, the intensity and frequency spectrum of sound in a room, the reverberation time in a room, noise criterion (NC) curves,[1] the modulation transfer function (MTF) of a room, and the speech transmission index (STI; Houtgast, Steeneken, & Plomp, 1980). The NC curves are a set of curves that were established in 1957 in the United States for rating indoor noise (Beranek, Blazier, & Figwer, 1971). The STI was developed by Houtgast and Steeneken (1973) to specify the amount of change that the acoustics of a room introduce to the transmission of a modulated signal in the room by characterizing these changes as a score from 0 to 1. A score of 1 would represent perfect transmission of a speech signal with no degradation; a score of 0 would represent that the signal was unrecognizable from the original signal after having been passed through the room. Changes in STI measurements were shown by Houtgast and Steeneken to correspond to changes in the average speech recognition performance of listeners in a room.

The NC and STI measures are not included as part of the criteria for a classroom meeting the ANSI S12.60 standard. However, they are used routinely by acoustic engineers to characterize the acoustic properties of rooms and their suitability for speech communication. The two measures have been included here to demonstrate, in as much detail as possible, the acoustic environment of the classrooms that were included in the study. Both the NC and STI measures were made when the classrooms were unoccupied.

For measurements made when class was in session, the TEF system was used to measure sound pressure level (SPL) over time; for the present study, the system was set to measure SPL with standard A weighting (dBA). Measurements of sound pressure levels were taken for 10 min in each location (locations as shown in Figure 1) while class was in session and the students were seated at their desks. The microphone was placed so that it pointed toward the teacher at a 0° azimuth and was placed at the height of the ear of a student (approximately 1 m high) when seated at a desk in the

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[1] For a given measured noise spectrum, the NC rating can be obtained by plotting noise measures made in octave bands from 63 Hz to 8000 Hz on the set of established NC curves. The noise spectrum is specified as having an NC rating that is the same as the lowest NC curve that is not exceeded by the spectrum of the noise.

classroom. With this capability, the TEF system was used to obtain measurements of ongoing audio signals during class sessions.

Because the version of the TEF system that was used for the measurements in the present study was an older unit, the sampling rate of the measurements was fixed at 512. This meant that for the 10-min recordings, each data point represented approximately 0.85 s. Individual speech sounds like phonemes range in length from approximately 20 ms to 280 ms (Kent & Read, 1992), and syllables are generally described as varying between 100 ms and 500 ms in length (Oller, 1986). Therefore, each 850-ms data point of the TEF measurement readout contains intensity information about several syllables, many phonemes, or multiple transient sounds produced in the classroom. This sampling rate reduces some of the variability of intensity that is present in a speech utterance. Although this reduces the amount of detail present in the TEF intensity measurement, it also made identification of peaks in the response less difficult for the observer in the classroom as noise sources that lasted for approximately 1 s or more would be captured by the TEF measurement but signals that had shorter durations than approximately 1 s were averaged in with other sounds that occurred simultaneously or in close temporal proximity.

An observer (the second author) was present during each 10-min TEF measurement. The 10-min block was divided into ten, 1-min-long sections, and the observer noted activity in the classroom during each 1-min section. In this way, the observer could compare his notes to the readout of the TEF system over each minute and identify the source of the peaks in intensity during the measure. Low intensity points were considered to be pauses in speech or other sound sources. These low points were considered to represent the occupied noise floor in the classroom and included the ambient noise of the room without the children (e.g., HVAC system noise, noise sources from the exterior of the classroom) and also the ongoing nonspeech noise of the children in the classroom. Peaks in the intensity measurement were classified into three categories based on the observers' written comments. These three categories included speech from the teacher; child speech that was directed to the entire class; and child group noise, which consisted of the children talking among themselves. The time of occurrence of additional brief noise events during the measurements, such as a child bumping his chair on a desk or the closing of the classroom door, were noted by the observer and were identified in the intensity measurement by matching the time of the occurrence of the event with a large peak occurring at the same time in the intensity recording made by the TEF system.

Procedure

The unoccupied classroom measurements were all made during the lunch period. For the occupied measures, measurements were made in the mornings, and each classroom was measured on a separate day. Once permission had been obtained to enter a classroom, the equipment was set up and the measurements were begun. The measurement microphone was positioned on a tripod and placed at various locations in the classroom while class was in session. The first measurement was taken at the back-center of the room at a place near a child's desk and at a height of the ear of the child who was seated at the desk. A 10-min measurement was taken at that point, and the examiner recorded comments on a chart about what was occurring generally during each of the 10 min (e.g., teacher lecturing or students working in groups). The microphone was then positioned at the left-back (6.4 m from teacher, left side of room), right-back (6.4 m from teacher, right side of room), left-center (3.2 m), middle-center (2.6 m), left-center (3.2 m), front-right (2.3 m), front-left (2.3 m), and front-center (1.5 m) of the classroom, again at positions near a student and at ear level (96.5–107 cm from the floor, depending on the height of the child's ear at a given placement in the room), and measurements were taken. When the class left for lunch, an unoccupied classroom measurement of the ambient noise, reverberation, and STI was taken to compare with the occupied measures that were made when class was in session. During these unoccupied measures, there was still activity in the building.

Measurements with the TEF system over 10-min intervals at each of the nine positions in the classroom were examined to determine the SNR in each classroom at each measurement position. Intensity levels in dBA were determined from the measurements by identifying the peak intensity values corresponding to the source of sound in the classroom when the measures were obtained. These peak values were averaged over the 10-min measures at each position. Averages were obtained for the teachers' speech, child speech, and child group noise levels. The source of the sound in the classroom was determined from the comments of the observer regarding activities in the classroom, minute by minute. An example of the TEF measurements and some sample comments of the observer are provided in Figure 2. The last 2 min of the recording shown in Figure 2 represent when the teacher turned off the classroom amplification system. The intensity levels represent measures at the back-left position of one classroom.

RESULTS

Unoccupied Measures

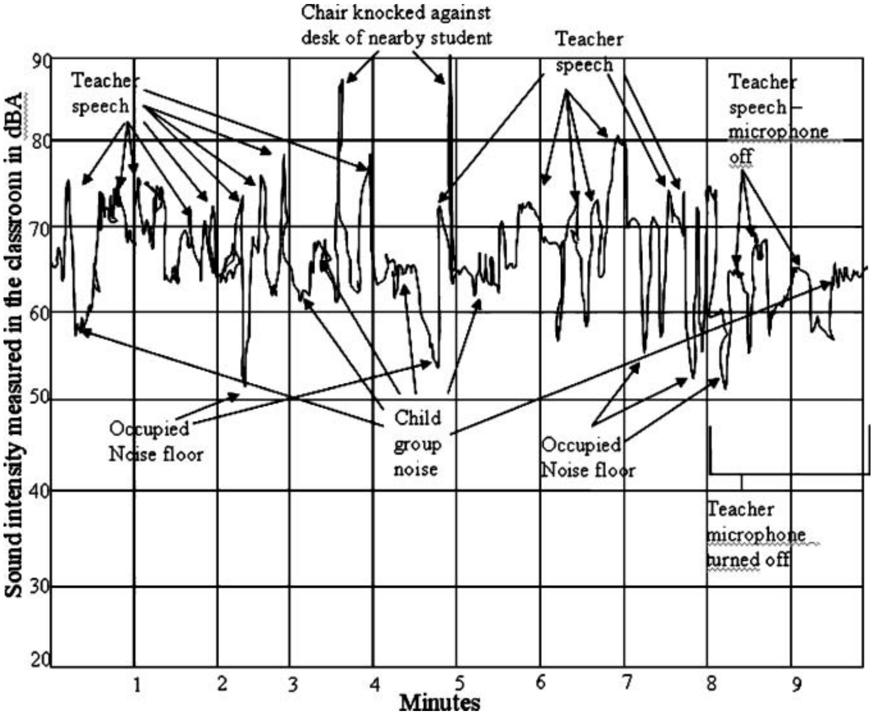
The results of the acoustic measures that were made during the lunch hour when each classroom was unoccupied are reported in Table 1. Reverberation times were based on TEF measures, which averaged the reverberation time measured in the octave bands of 500 Hz, 1000 Hz, and 2000 Hz. NC curves and STI values are also reported. The reverberation times and noise measures in the 4 unoccupied classrooms each met the ANSI S12.60 standard for acoustic conditions in elementary school classrooms. The STI values reported for each classroom in Table 1 represent "excellent" acoustic transmission of a speech signal across the unoccupied classroom, according to the scale developed for the STI by Houtgast et al. (1980).

Occupied Measures—SNR of Teacher Speech

The average peak value for sounds that were classified as child group noise in the 4 classrooms ranged from 58 dBA (*SD* = 4.2) in 1 classroom to 64 dBA (*SD* = 5.9) in another (see Table 2). Occasional intermittent noises (e.g., door slamming or dropping of books) were not included in the calculation of child group noise, but their presence resulted in a large range of intensity values in each classroom (from 42 dBA for the nonspeech noise floor in 1 classroom to a 100-dBA peak in another classroom).

The mean of the intensity peaks that were identified as child group noise for each classroom were compared to the mean of the

Figure 2. One 10-min measurement of intensity in dBA in a classroom at a position near the center of the classroom. The teacher was located at the front of the classroom and an observer noted the source of sounds in the classroom over the 10-min period. Some of the identified sources of sound are included in the figure. The measure was taken with the teacher using a classroom amplification system as she spoke to the class, except for the last 2 min of the measurement. For the last 2 min, the microphone for the classroom amplification system was turned off.



intensity peaks of teacher-generated speech in the classroom, and the resulting SNR values for each room are reported in Table 3. The mean intensity values of the speech of each teacher without the classroom amplification system resulted in an average 3.5 dB SNR across the 4 classrooms; amplified teacher speech was 13.5 dB more intense than the average child group noise across the 4 classrooms. The SNR of the unamplified speech of the teachers varied from +1 dB SNR in 1 classroom to +6 dB SNR in another. When the classroom amplification system was used, the SNR values ranged from +11 dB SNR to +15 dB SNR across the 4 classrooms.

To demonstrate the variability of speech and noise levels across a single classroom, Table 4 contains the mean SNR for each of the nine measurement positions in 1 classroom without the use of the classroom amplification system. As the measures happened at different times and with different activities going on in the classroom, the comments about what was happening in the classroom are important to consider when comparing noise levels and SNR values in the table. The range in SNR across the classroom was large (+3.0 dB to –17.6 dB). When measures were taken at different positions in this particular classroom on similar types of activity occurring (i.e., when the teacher was lecturing as occurred for measurement positions 1 through 5, and 8), the differences in SNR (+3 dB to +9 dB) followed closely expected differences due to the student's distance from the teacher. Positions 7 and 9 showed poor SNR values (–17.6 dB and –8 dB), which would be expected as the teacher's speech in these measurement intervals was limited

Table 1. Reverberation times (RT 60) in seconds, noise criteria (NC) curves, mean ambient noise level in dBA, and speech transmission index (STI) values (which are a rating between 0 and 1 of signal transmission quality where 1 is the optimal score) for 4 classrooms, measured with each classroom empty but with normal activity in the school buildings. Each measure was calculated by TEF System-20 software from an acoustic measurement of a 20-s broadband signal that was generated by the TEF system software and played through a classroom amplification loudspeaker in each classroom.

	Classroom 1	*Classroom 2*	*Classroom 3*	*Classroom 4*
RT 60 in seconds	.35	.29	.36	.28
NC curve in dB	35.00	30.00	35.00	30.00
Mean noise level in dBA	34.00	31.00	35.00	31.00
STI	0.87	0.92	0.86	0.93

Table 2. Minimum, maximum, and average child group noise intensity levels as measured with the TEF System-20 analyzer in dBA in 4 elementary school classrooms when class was in session. The standard deviations of the averages of the child group noise peaks measured in the classrooms are reported in parentheses.

Measurement	*Classroom 1*	*Classroom 2*	*Classroom 3*	*Classroom 4*
Minimum (dBA)	44	44	43	42
Maximum (dBA)	97	100	68	85
Average (dBA)	58 (4.2)	58 (6.1)	59 (4.9)	64 (5.9)

to one-on-one communication with students who were far from the measurement position of the microphone in the room and the students were allowed to communicate with one another as they worked on their individual projects. The teacher speech peaks from the 7th position were not considered as part of the calculation of the SNR of the teacher's speech to the child group noise because all of the utterances were directed during this measurement position to individual children. However, the peaks of the teacher's speech from the 9th measurement position were included in the average because much of the speech was directed toward more than one student.

Table 5 shows the mean and standard deviations of measures of teacher speech intensity and child group noise for nine measurement positions in a room where the teacher used a classroom amplification system. The SNR of teacher speech to child group noise in this situation averaged approximately 13 dB across the eight measures where the teacher addressed the class. The lowest SNR was observed during a period when the children were working in groups and the teacher roamed around the room, occasionally making comments to the class about the activities of certain groups. The ambient noise during this measure was 68 dBA, which was 9 dB more intense than the overall average child group noise measured in this classroom. However, with the classroom amplification system, the teacher was able to maintain her speech 5 dB above this noisy situation. Also of note was that the SNR for children who were seated at the back of the classroom when the teacher was lecturing was very similar to that for children who were seated in the front of the class when the teacher was lecturing.

Occupied Measures—SNR of Child Speech to the Class

The measurement that was made in the left-front of the same classroom as reported in Table 3 was made during a 10-min period when students were reading aloud from their desks. Measurements were made for 4 different students reading at four different distances from the measurement microphone (see Figure 1). The intensity of the students' speech while reading varied from 58 dBA (*SD* = 5.5) at a distance of 2 ft to 46 dBA (*SD* = 6.2) at a distance of 12 ft. Measures were also made at 3 ft and 6 ft, with measured values being 56 dBA (*SD* = 3.2) and 55 dBA (*SD* = 5.3), respectively. If the mean ambient noise level in the classroom is close to the mean of 58 dBA, other students in the classroom will receive the speech from their fellow student at a 0 dB SNR at best, and possibly at a –10 dB to –15 dB SNR for those students who are farthest away from the student who is reading or making a comment. In the case of these student readings, the mean ambient noise level was measured to be 49 dB at the left-front position of the classroom. This would result in an SNR of between +9 dB to as poor as –3 dB for the student speech at the four different student positions. The SNR of student speech from these four positions when the pass-around microphone was used by the students to make comments was +13 dB in the left-front position of the classroom. Because only one microphone and TEF system were available, simultaneous measurements of the SNR of student communication at different positions in the classroom were not possible.

DISCUSSION

The primary purpose of this investigation was to measure the intensity levels of speech and noise so that the SNR could be estimated across 4 classrooms when class was in session, with and without the use of a classroom amplification system. The results of the measurements showed variability in the intensity levels of the teacher's speech across the classroom (see both mean data in Table 3

Table 3. Mean child group noise intensities (dBA) in 4 elementary school classrooms when class was in session. Also, mean unamplified and amplified teacher speech intensity values are reported. The SNR (in dB) of the teacher's voice as compared to the average intensity of the child group noise in each of the 4 classrooms for both the unamplified and the amplified conditions are also shown. Standard deviations of each mean are reported in parentheses next to their corresponding mean value.

Measurement	*Classroom 1*	*Classroom 2*	*Classroom 3*	*Classroom 4*
Child group noise average (dBA)	58 (4.2)	58 (6.1)	59 (4.9)	64 (5.9)
Unamplified mean teacher speech (dBA)	61 (3.0)	62 (6.5)	65 (4.9)	65 (3.4)
Amplified mean teacher speech (dBA)	71 (4.1)	71 (3.5)	70 (4.6)	79 (5.1)
Unamplified SNR (dB)	+3	+4	+6	+1
Amplified SNR (dB)	+13	+13	+11	+15

Table 4. Noise floor minimum values in dBA and nonspeech intensity maximum peaks in dBA are reported for nine 1-min measurement periods at nine positions in 1 classroom. Also, mean peak intensity values of child group noise in dBA and the mean *unamplified* teacher speech intensity in dBA with standard deviations in parentheses are shown for the same nine measurements. The SNR of the teacher's voice in reference to the child group noise intensity is also given. One general comment of the observer for each of the nine measurement periods is provided.

Measurement location in classroom	*Noise floor (dBA)*	*Nonspeech peak (dBA)*	*Mean child group noise (dBA)*	*Mean teacher speech level–unamplified (dBA)*	*SNR of teacher to child group noise (dB)*	*General comment about the source of sound during the minute*
1. Back-center	41	85	57 (4.4)	60.0 (3.1)	+3	Teacher lecturing
2. Left-back	39	94	54 (3.7)	57.7 (3.0)	+3.7	Teacher lecturing
3. Right-front	41	94	56 (4.4)	65.0 (3.4)	+9	Teacher lecturing
4. Left-center	40	102	61 (2.9)	66.0 (2.9)	+6	Teacher lecturing
5. Right-center	40	83	59 (3.1)	65.0 (2.5)	+6	Teacher lecturing
6. Left-front	38	78	49 (6.7)	NA	NA	Students reading aloud
7. Front-center	32	87	56 (3.9)	38.4 (6.1)	–17.6	One-on-one work
8. Right-back	44	100	58 (3.3)	61.0 (3.5)	+3	Teacher lecturing
9. Center-center	49	89	67 (5.6)	59.0 (5.2)	–8	Children working on a project

Note. Measurements were not made simultaneously.

for teacher speech and also the reported *SD*s) when the classroom amplification system was not used, most likely due to the distance between the measurement and the teacher. This result confirms often-described findings that many children across a classroom may receive low-level speech input from teachers (Bradley & Sato, 2004; Jones et al., 1989; Leavitt & Flexer, 1991; Smaldino, Green, & Nelson, 1997). Previous research concerning speech recognition by children at different SNRs has shown that children need better SNRs than adults in order to be able to recognize speech with good accuracy (Elliott, 1979; Finitzo-Heiber & Tillman, 1978). Recommended SNRs for optimal speech recognition for children with normal hearing range from 12 dB (Finitzo-Hieber & Tillman, 1978) to 15 dB (Bistafa & Bradley, 2000). Speech recognition measures were not made for the present study, but the mean SNRs for the teacher's speech in the present study when the classroom amplification system was not used ranged from +1 dB to +6 dB. These values are well below the recommended SNR values for optimal speech recognition.

The SNR estimates of the present study differed from those in previous studies but were generally comparable to those of Houtgast (1981; +1 dB to +14 dB) and Markides (1986; –16 dB to +11 dB). The data from Hodgson et al. (1999) showed an SNR of +8 dB, but those measurements were made in university classrooms and so are not considered to apply to the case of elementary schoolchildren. The data from Sato and Bradley (2004) showed an overall SNR of +11 dB measured in elementary school classrooms. Future research should be carried out to determine if the source of the differences in the SNR estimates of these studies is related only to the particular classrooms measured or if the method of SNR estimation played a significant role in the differences observed.

The measurements obtained to meet the second purpose of this study (to compare SNRs with and without the use of a classroom amplification system) showed an increase of approximately 10 dB in the SNR for the teacher's speech when the classroom amplification system was used over when it was not used. Also, the data showed that the SNR was maintained at a level (approximately

Table 5. Noise floor minimum values in dBA and nonspeech intensity maximum peaks in dBA are reported for nine 1-min measurement periods at nine positions in 1 classroom. Also, mean peak intensity values of child group noise in dBA and the mean *amplified* teacher speech intensity in dBA with standard deviations in parentheses are shown for the same nine measurements. The SNR of the teacher's voice in reference to the child group noise intensity is also given. One general comment of the observer for each of the nine measurement periods is provided.

Measurement location in classroom	*Noise floor (dBA)*	*Nonspeech peak (dBA)*	*Mean child group noise (dBA)*	*Mean teacher speech level–amplified (dBA)*	*SNR of teacher to child group noise (dB)*	*General comment about the source of sound during the minute*
1. Back-center	42	89	56 (3.9)	70 (4.5)	+14	Teacher lecturing
2. Left-back	37	100	55 (4.6)	70 (5.0)	+15	Teacher lecturing
3. Right-front	36	89	47 (4.4)	NA	NA	Quiet reading
4. Left-center	35	87	56 (4.6)	71 (3.9)	+15	Teacher lecturing
5. Right-center	41	92	63 (7.2)	74 (8.2)	+11	Class discussion
6. Left-front	44	99	55 (3.9)	69 (4.3)	+14	Teacher lecturing
7. Front-center	40	85	68 (6.2)	73 (6.1)	+5	Group work
8. Right-back	40	92	54 (4.5)	70 (4.4)	+16	Teacher lecturing
9. Center-center	38	88	57 (3.8)	70 (4.9)	+13	Teacher lecturing

Note. Measurements were not made simultaneously.

+13 dB) that is close to the level considered to be optimal for speech recognition (Bistafa & Bradley, 2000; Finitzo-Heiber & Tillman, 1978). This optimal level was shown to be present for students in both the front and the rear of the classroom. Other research has demonstrated that speech recognition is improved for listeners when high, positive SNRs are present when classroom amplification is used (e.g., Blair, Myrup, & Viehweg, 1989; Crandell, Holmes, Flexer, & Payne, 1998; Smaldino et al., 1997). However, no speech recognition measures were made in the present study to demonstrate improved speech recognition among listeners when the classroom amplification system was used.

The SNR improvement from a classroom amplification system, demonstrated by the measurements in these 4 classrooms, must be tempered by some limitations to the method of the study. The selection criteria used to choose classrooms for the study (i.e., only fourth-grade classroom in schools that were built within the past 10 years) resulted in the choice of 4 classrooms with excellent acoustic properties for speech communication, as determined by the unoccupied measures that met the ANSI S12.60 standard for classrooms. Some authors have argued that classroom amplification systems may not provide good benefit for children when the acoustics of the classroom are poor (Boothroyd, 2004; Lubman, 2005). Due to the selection of only classrooms with acoustic properties that met the ANSI S12.60 standard, the results of the present study may not apply to classrooms with poor acoustic properties. However, the present study does demonstrate that even in classrooms where the ANSI S12.60 standard is met, classroom amplification systems may be necessary to ensure that an optimal SNR is present for listeners across the classroom.

Also, if the unoccupied noise level of a classroom is substantially higher than that recommended by the ANSI S12.60 standard, the noise levels in the occupied condition may exceed those of the present study, which were already deemed by us to be high. In this case, the intensity level needed for the teacher's speech to be 10 dB to 15 dB more intense than the occupied noise levels of such a classroom may be intense enough to cause concern about the risk of damaging the hearing sensitivity of the children in the classroom. Further research in classrooms with poor unoccupied acoustic properties and high noise levels, and where a classroom amplification system is used, will be needed to address these concerns.

The data collected to meet the third purpose of the study reveal the additional SNR advantage that children may have when a handheld microphone is used during class discussions or oral reading. If the information that students have to share is important for all of the students to hear, then their voices need to be amplified when they are contributing something to the class. This research suggests that by not using classroom amplification, many children in the class are constantly hearing information at low SNR levels. This may affect their learning in ways that are not clear at the present time. It should be noted that the SNR benefit that was measured in this study for the classroom-amplified student communication was only measured at one location in a classroom. Measures across the classroom were not made to verify that the amplified student comments were received at the desks of the students with a consistent SNR, as was shown for the teachers' voices. However, based on the consistent SNR that was observed for the teachers' speech with the classroom amplification system, it was assumed that the same applied to the student comments.

The direct observation method that was used to estimate the SNR in the 4 classrooms of the present study was chosen because it was believed to be effective in specifying the sources of sound that can influence sound intensity measurements. The authors believe that the method was successful in identifying the sources of sound during the measurements, and therefore estimating the SNRs accurately. However, only simultaneous video and audio recordings would be able to confirm the accuracy of the observer in specifying the sound sources in the classroom and the subsequent SNR accuracy. Future research may be warranted to confirm the accuracy of the method used here. The direct observation method is likely no less reliable at specifying the sources of sound in a room than other methods that use statistical sound distributions to identify sound sources in the classroom (Hodgson et al., 1999).

One weakness of the data from the present study in describing the variability of the intensity of the teacher's speech and that of the students in a particular classroom is that simultaneous measures at different positions were not made. To accurately describe the variability that exists across the classroom when the teacher is speaking or some other event is occurring, measurements at multiple points across the classroom would best characterize the variability that exists at a specific time. This limitation must be considered when generalizing the results of the present study to variability that might exist in classrooms generally.

CONCLUSION

The use of a classroom amplification system in 4 elementary school classrooms provided a high SNR, on average, of +13 dB for students across each classroom. The measurement of this SNR at nine different measurement locations across the 4 classrooms provides evidence that, at least for classrooms with good unoccupied acoustic properties, the use of a classroom amplification system can provide excellent acoustic conditions for speech communication by a teacher to all of the students in a classroom. Also, the results of measurements that were made when students were reading demonstrated that when students do not use a classroom amplification system, the SNR of their voices for their fellow students may be poor. The use of a handheld microphone coupled to the classroom amplification system in the present study was successful in improving the SNR of student speech.

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