The Effect of Room Acoustics and Sound-Field Amplification on Word Recognition Performance in Young Adult Listeners in Suboptimal Listening Conditions

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Purpose: To compare the speech recognition performance of young adult listeners with normal hearing in 2 college classrooms, only 1 of which met American National Standards Institute (ANSI) S12.60-2002 acoustic standards. Also, differences in speech recognition performance were compared in both classrooms with and without the use of a classroom amplification system. The speech was presented at low intensity to simulate listening in the rear seats of a large college classroom.
Method: Listeners were randomly assigned seats in the 2 classrooms, and Northwestern University Auditory Test No. 6 (NU-6) words were presented via a loudspeaker from the front of the classroom for all listening conditions as well as through a sound-field infrared system with ceiling-mounted speakers during the amplified condition.
Results: Results showed statistically significant differences in speech recognition performance between classrooms, with and without classroom amplification, and across the rows of each classroom when the classroom amplification system was not used.
Conclusions: These results demonstrate how meeting the ANSI S12.60-2002 standard, which was written for elementary school classrooms, can benefit young adult listeners in postsecondary classrooms. Also, classroom amplification was shown to improve speech recognition for students across the classroom in both acoustically poor and acoustically sound classroom environments.

Key Words: classroom acoustics, adults, speech recognition

The American National Standards Institute (ANSI) recently published minimum acceptable values of noise and reverberation for kindergarten through 12th-grade classrooms (ANSI, 2002) where speech communication is critical. The ANSI S12.60-2002 standard specifies acceptable maximum levels of reverberation, measured as reverberation time (RT), as 0.6 s for small elementary school classrooms (with total volume less than 283 m^3) in the frequency range from 500 Hz to 2000 Hz and 0.7 s for moderate size classrooms (with volume between 283 m^3 and 566 m^3). Also, ambient noise levels of no more than 35 dBA are considered acceptable in the standard.

ANSI S12.60-2002, if implemented, should have a positive influence in building elementary schools and classrooms that will be better suited for speech communication. However, the cost to build or modify school classrooms to meet the ANSI standard has been viewed as prohibitive by some educators and industry groups. A report commissioned by the Air Conditioning and Refrigeration Institute (n.d.) measured the acoustic conditions in 16 schools in Minnesota and estimated that the cost to renovate the schools to meet the ANSI standard would range from \$4.78 to \$14.80 per square foot. This represents a 4% to 16% increase in the cost of building a new school. More conservative estimates place the additional cost of meeting the ANSI standard in new

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schools between 1% and 5% (Nelson, 2000). Considering that the cost of building a modern elementary school building is in the millions of dollars, even increases in the 1% to 5% range represent substantial dollar amounts.

Because of the significant costs involved with meeting the ANSI standard for classroom acoustics, many elementary schools have chosen to install classroom amplification systems. Classroom amplification systems (sometimes referred to as sound-field amplification systems) are similar to small, wireless public address systems. They consist of a microphone that the teacher wears, a transmitter, and one or more loudspeakers positioned in the room to amplify the teacher's voice over the noise present in the classroom. Ranging in cost from $800 to $2,000 per classroom, classroom amplification systems represent a potential remedy for classroom acoustic problems (Crandell, 1996; Jones, Berg, & Viehweg, 1989; Mendel, Roberts, & Walton, 2003) that is less expensive than making the acoustic modifications necessary to meet the ANSI standard. Data have been collected indicating that speech recognition performance is improved when classroom amplification is present. These speech recognition 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), children with Down syndrome (Bennetts & Flynn, 2002), and children with mild hearing loss (Neuss, Blair, & Viehweg, 1991).

Acoustical engineers such as Lubman (2005) have criticized the use of classroom amplification as a solution to the problem of poor classroom acoustics by maintaining that the classroom amplifiers are unnecessary if classrooms meet the ANSI standard. Lubman (2005) also argued that the amplified signal from a classroom amplification system may pass through to adjacent classrooms. Also, concern has been expressed that amplification has limited benefit in classrooms with RTs that exceed those recommended by the ANSI standard. This last objection is supported by Boothroyd (2004), who explained that classroom amplification is an effective option if the primary acoustic problem in the classroom is background noise but stated that "this technology is less effective when the primary problem is reverberation" (p. 164).

Postsecondary Classroom Acoustics

Even though the ANSI S12.60-2002 standard was written for elementary school classrooms, some studies have compared measures of classroom acoustic quality in postsecondary classrooms with the ANSI S12.60-2002 standard to demonstrate that the acoustics for speech communication in these postsecondary classrooms are less than optimal. In 2003, measurements of 145 classrooms were recorded for background noise levels and RTs at one Midwestern university (Kelly & Brown, 2002). None of the classrooms measured met the American Speech-Language-Hearing Association (ASHA) recommended unoccupied noise level of 30 dBA, and only one of the classrooms met the ANSI S12.60-2002 standard of 35 dBA. Additionally, none of the classrooms met either the ASHA (1995) recommended RT of 0.4 s or the ANSI S12.60-2002 recommended RT of 0.6–0.7 s. Also, Hodgson (1999) measured the early decay time (EDT) and background noise levels of 30 classrooms at a university in Canada and reported that 93% of the classrooms exceeded an EDT value of 0.5 s, and 97% of the classrooms exceeded a 35 dBA ambient noise level. Based on these available research findings, it is likely that many college classrooms do not meet the ASHA (1995) or ANSI S12.60-2002 standard, meaning that the acoustic properties of these postsecondary classrooms are not optimal for speech communication.

Listening Conditions

Hodgson, Rempel, and Kennedy (1999) provided information about the acoustic conditions in medium-sized to large auditoriums, which are common learning environments for many undergraduate courses at universities across North America. Hodgson et al. measured sound intensity levels in 11 college classrooms (518 m^3 on average) at various points across the rooms. During the measurements, 108 students were present, on average, in the classrooms. The distribution of intensities over time allowed the researchers to estimate the intensity level of (a) the professor teaching in the room, (b) the ambient noise from the heating, ventilation, and air conditioning (HVAC) system, and (c) the noise from the students in the room. On average, the voice of the professor in the 11 classrooms was 50.8 dBA, while the HVAC and the student noise averaged 40.9 dBA and 41.9 dBA, respectively. The total competing noise measured across classrooms was approximately 44 dBA. The average level of 50.8 dBA for the professor's voice in Hodgson et al.'s study was approximately 10 dB less intense than the average level of a teacher's voice as measured in elementary school classrooms (Picard & Bradley, 2001). This large difference is certainly due in large part to the greater teacher–student distance that exists in auditoriums as compared with the teacher–student distance that exists in an elementary school classroom. It is not unreasonable to estimate that listeners in the rear of college auditoriums must sometimes listen to the professor's voice at intensity levels less than 50 dBA.

Research has demonstrated that adults perform better than children on speech recognition tasks in background noise (Elliott, 1979; Johnson, 2000). Based on research concerning the acoustic conditions of elementary school classrooms (Picard & Bradley, 2001), it is probable that most young adults entering postsecondary education are the survivors of a poor acoustic learning environment. Perhaps postsecondary students have learned to cope with a poor acoustic learning environment with some success and therefore do not require that the acoustic conditions meet the ANSI S12.60-2002 standards. Or do the poor acoustic conditions reported to exist in postsecondary classrooms result in poor speech recognition for college-age listeners? Does meeting the maximum allowable values of RT and ambient noise in a college classroom that have been recommended by ANSI S12.60-2002 for primary grade listeners result in measurable benefits for young adult listeners? It is likely that meeting the ANSI standard in postsecondary classrooms would improve speech recognition. However, is the benefit enough to justify the cost? If there is benefit, does this benefit extend to those listeners in the rear of midsize to large college classrooms who must listen to quiet speech of sometimes less than 50 dBA? Also, in light of the concerns raised about the benefits of classroom amplification when reverberation levels are high, is classroom amplification an appropriate solution to the suboptimal acoustic environments in college classrooms described by Kelly and Brown (2002) and Hodgson (1999)?

Purpose

The purpose of the present study was to measure the speech recognition performance of young adult listeners in two college classrooms. One classroom had acoustic characteristics that met the ANSI S12.60-2002 standard, and the other classroom had acoustic characteristics that did not meet the ANSI S12.60-2002 standard. Additionally, in each of these two college classrooms, speech recognition performance from the same young adult listeners was observed both with and without the use of an infrared classroom amplification system to compare the relative benefits of meeting the ANSI S12.60-2002 standard with the use of amplification. It was further decided to present the speech at a low intensity level (less than 50 dBA), which is representative of what many postsecondary listeners might experience if they were seated in the back half of a midsize to large college classroom (Hodgson et al., 1999).

Two classrooms at Utah State University of similar physical dimensions were chosen. One classroom had RT and ambient noise values in the unoccupied condition that were poorer than the maximum values allowed by the ANSI S12.60-2002 standard. In contrast, the second classroom had measured values that were within the guidelines of the standard. Each classroom was equipped with a classroom amplification system from Audio Enhancement with four loudspeakers mounted in the ceiling tiles of the classroom. Data were collected to answer five research questions:

1. Does the speech recognition performance of young adult listeners improve when listening in a college classroom with acoustic properties that meet the ANSI S12.60-2002 standard as compared with listening in a college classroom with acoustical properties that do not meet the standard?
2. Does the speech recognition performance of young adult listeners improve when listening in a college classroom with a classroom amplification system as compared to listening in the same classroom without the classroom amplification system?
3. Is there a difference in the benefit for speech recognition that young adult listeners receive from a classroom amplification system if the college classroom meets the ANSI S12.60-2002 standard as compared with a college classroom that does not meet the standard?

Two additional research questions were investigated to provide more specific information about the benefit that postsecondary listeners received from either the ANSI S12.60-2002 standard or the classroom amplification system. It may be that in a classroom with an amplification system, some listeners who are closer to the loudspeakers benefit more than those who are farther from the loudspeaker. This is an important consideration for school administrators considering the purchase of a classroom amplification system. Also, meeting the ANSI S12.60-2002 standard addresses the acoustic problems of noise and reverberation, but there is still the issue of distance from the speaker. This can be an issue particularly in college classrooms, which tend to be larger than the typical elementary school classroom for which the ANSI S12.60-2002 standard was developed. Thus, we chose to investigate whether listeners across the classroom received similar benefit for speech recognition from listening in a classroom that was compliant with the ANSI S12.60-2002 standard. Therefore, the fourth and fifth research questions were:

4. Does the speech recognition performance of young adult listeners differ depending upon the row in which they are sitting in a college classroom that meets the ANSI S12.60-2002 standard?
5. Does the speech recognition performance of young adult listeners differ depending upon the row in which they are sitting when listening with a classroom amplification system in a college classroom?

Method

Participants

Fifty-three students (28 male) at Utah State University volunteered to participate in this study. Participants were informed of the opportunity via a campus flier. Those eligible for this study were in good general health, had hearing within normal limits, were between the ages of 18 and 40 ($M = 23$), were native English speakers, and had no history of learning disabilities or speech-language delays. Selection criteria included responses at 20 dB HL, at 250, 500, 1000, 2000, 4000, and 8000 Hz, and normal tympanograms. In addition, each participant completed a medical questionnaire. All participants read and signed an informed consent agreement prior to the test session that had been approved by the institutional review board for the protection of human subjects at Utah State University. Participants were compensated for their involvement in the study.

Instrumentation

Research instruments consisted of a Larson Davis 800B sound level meter, a Panasonic RX-ES25 CD player, an Auditec CD recording of the Northwestern University Auditory Test No. 6 (NU-6) lists (Tillman & Carhart, 1966), a Techron TEF20 time/energy/frequency analyzer, an Audio Enhancement ULT2000 Ultimate Infrared Classroom System, and a Macintosh laptop computer. The sound level meter was used to measure the background noise of each classroom and the volume level of the CD player, and to verify the signal-to-noise ratio (SNR) gain during the amplified testing session. The CD player was used to deliver the NU-6 lists to the students in unamplified and amplified test conditions. The TEF20 was used to measure unoccupied classroom acoustic characteristics including RT. The infrared system provided an amplified signal within the classroom. The laptop computer controlled the TEF20 system.

The frequency response of the loudspeaker of the CD player was measured in a sound-treated audiometric test suite (IAC 1400) using an Ivie IE-30A real-time analyzer with an input of pink noise and measured with a 1/3 octave band filter and found to be flat (±2 dB) from 250 to 8000 Hz. The Larson Davis sound level meter was used to measure the output of the CD player in each classroom using an 8-talker babble recorded on a CD that had the same root-mean-square intensity level as that of the Auditec recording of the NU-6 words. The volume control of the CD player was set in each classroom to produce an average output of 65 dBA measured at 6 in. from the loudspeaker.

Test Environment

Two classrooms located on the Utah State University campus were selected for their acoustic characteristics. Classroom 1 (hereafter referred to as the "poor acoustic classroom") measured 22 ft 9 in. (length) × 22 ft 6 in. (width) × 8 ft 8 in. (height). Other characteristics were wall-to-wall carpet, acoustic ceiling tile, dry board, painted walls, and two wooden doors (no windows). Classroom 2 (hereafter referred to as the "acoustically sound classroom") had dimensions of 24 ft 2.5 in. (length) × 17 ft 1 in. (width) × 9 ft 6 in. (height), with carpet, acoustic ceiling tile, dry board, painted walls, three windows, and one door. The distance between adjacent speakers in both classrooms was 10 feet (see Figure 1). The classrooms were smaller than the average classrooms on the Utah State University campus. However, their acoustic characteristics allowed for comparison of listening under good and poor classroom acoustic conditions.

Measurements

The ambient noise level of each classroom was measured in the center of the room with the Larson Davis 800B sound level meter. RT values were measured with the TEF20 system by means of presenting a broadband noise from a loudspeaker and measuring with an omnidirectional microphone connected to the TEF20. The RT measures reported in the present study were made in the octave bands of 500, 1000, and 2000 Hz, and averaged across these three frequency bands. Measurements of the two unoccupied classrooms used in this study revealed an ambient noise level of 44 dBA and an RT of 0.76 s for the poor acoustic classroom. Neither measure met the ANSI S12.60-2002 standard. By comparison, the acoustically sound classroom had a noise level of 34 dBA and an RT of 0.53 s, both measures being within the limits recommended by the ANSI standard. The HVAC system was always on in the poor acoustic classroom, whereas the HVAC system in the acoustically sound classroom did not turn on the entire time of the study.

A series of measurements were made in each classroom (unoccupied) to obtain SNR estimates at each row of seats without the use of the classroom amplification system and with the amplification system turned on. Initially, measurements were made with the classroom amplification system turned off at distances of 6, 10, 14, and 18 ft (rows 1, 2, 3, and 4, respectively) from the CD player loudspeaker and centered between the two sidewalls. These distances represented the front edge of student desks arranged in four equidistant rows. The sound level meter was placed on a tripod, and the microphone was elevated to a height of 45 in., the approximate ear level of an adult seated at a student desk. The NU-6 word list recording served as the speech signal. The instantaneous peaks of each of the NU-6 words were taken and averaged across a list of 50 words to obtain an average speech intensity value. Measurements of ambient noise were also made, and SNRs were calculated (see Tables 1 and 2).

The same measures were made in each classroom with the classroom amplification system turned on. Measurements were made at each of the ceiling-mounted speakers. The speech signal (multitalker babble) from the CD player was routed through the infrared sound-field amplification system via an input jack in the base station. The volume level was set to produce an output of 65 dBA at 6 in. from each speaker.

Figure 1. Schematic of the classroom configuration in the poor acoustic classroom. Circles in bold represent the placement of the ceiling speakers.

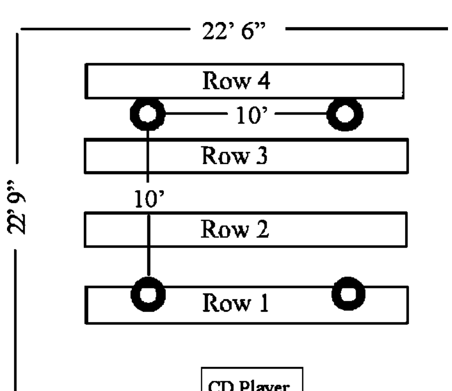


Table 1. Summary of sound level measurements in the poor acoustic classroom and the acoustically sound classroom with a recorded speech signal of Northwestern University Auditory Test No. 6 (NU-6) words presented through a CD player at the front of the room.

	Signal output (dBA)	Ambient noise (dBA)	Signal-to-noise ratio (dB)
Poor acoustic classroom			
Row 1	48	44	+4
Row 2	48	44	+4
Row 3	47	44	+3
Row 4	46	44	+2
Acoustically sound classroom			
Row 1	48	34	+14
Row 2	48	34	+14
Row 3	46	34	+12
Row 4	45	34	+11

Note. The sound level meter microphone was placed at a height of 45 in. at each desk.

Table 2. Summary of sound level measurements in the poor acoustic classroom and the acoustically sound classroom with a recorded speech signal of NU-6 words routed through four ceiling-mounted speakers.

	Signal output (dBA)	Ambient noise (dBA)	Signal-to-noise ratio (dB)
Poor acoustic classroom			
Row 1	58	44	+14
Row 2	59	44	+15
Row 3	58	44	+14
Row 4	58	44	+14
Acoustically sound classroom			
Row 1	58	34	+24
Row 2	59	34	+25
Row 3	58	34	+24
Row 4	58	34	+24

Note. The sound level meter microphone was placed at a height of 45 in. at each desk.

Again, measurements of the NU-6 recording were made at the front of each of the four rows as described earlier and at a height of 45 in. The average level of the signal for each row in the amplified condition was 58–59 dBA (see Table 2).

The NU-6 (Tillman & Carhart, 1966) was used to measure the word recognition ability of the participants in this study. The test included four word lists, composed of 50 words each. The NU-6 was chosen because the presence of monosyllabic words, without contextual reference, created a challenging environment in which word recognition, not knowledge, was assessed.

Speech Intensity Level

The relatively low intensity of the speech in this study served two purposes. One, the low level of the speech served to reduce the likelihood of ceiling effects on the word recognition task for the normal hearing adult listeners who participated in this experiment. Two, the intensity level without amplification was 47.25 dBA on average across the listener positions in the room. This is 3.55 dB less intense than the average of 50.8 dBA reported by Hodgson et al. (1999) for college professors' speaking level during lectures. There are important differences between the size of the classrooms that Hodgson et al. (1999) measured in their study and those used in the present study. The size of a classroom will influence the intensity of speech within the room due to the distance that the speech needs to travel. Also, speakers in larger or noisier classrooms will likely adapt the intensity of their voice to the listening situation so as to maximize the audibility of their message (Lombard, 1911). However, the data from Hodgson et al. (1999) demonstrate that postsecondary listeners are sometimes required to listen to speech at relatively low intensity levels (50.8 dBA on average), and so the intensity levels used in the current study are within what might occur for many listeners in the back half of midsize to large university classrooms. The use of such low intensity levels limits the generalizability of the results to the "average" listening situation in college classrooms but allows the benefits of room acoustics and classroom amplification to be tested under conditions that are likely to exist in many large college classrooms across North America.

Procedures

Student desks were positioned in four rows within the classroom (see Figure 1). The floors in both classrooms were temporarily marked to ensure that the distance between adjacent desks was constant. The distance from the front of row 1 to the front of row 2 was 4 ft. Seating capacity of the two classrooms coupled with the sample size dictated that participants be assigned to one of two groups. To include as many participants as possible, the two classrooms were scheduled on 2 consecutive days. Participants were assigned to a group based on their availability to participate on one of these days. Both groups consisted of listeners with normal hearing. Other than a difference in the numbers of participants, no other difference between the groups was known to the researchers. Group 1 consisted of 22 participants (6 male and 16 female) and was tested first. Group 2 comprised 31 participants (22 male and 9 female), and these listeners were tested on the second day. On each of the 2 days, an hour-long test session was conducted in unamplified and amplified conditions in each classroom. The order of testing in the classrooms was counterbalanced. This meant that on the first day, Group 1 was initially tested in the poor acoustic classroom and then in the acoustically sound classroom while Group 2 was tested in the acoustically sound classroom first. Each group was tested first in the unamplified condition followed by the amplified condition. The fact that the unamplified condition was presented first on both occasions may have resulted in an order effect for the study. The listeners were not subjected to long listening times, and therefore the magnitude of such an effect was deemed to be small. Nevertheless, the results must be viewed with the idea that some order effect may be present.

Each participant was seated at a desk. The CD player was placed at the front of the class at a distance of 6 ft from the front row and was used for both the unamplified and amplified test conditions. Participants were given written instructions for the word recognition task. An Auditec version of the NU-6 words was presented from the CD player loudspeaker, and participants were instructed to write down each word they heard. Fifty words were presented in each test condition. An answer sheet labeled with the participant's unique alphanumeric code, classroom number, and a blank NU-6 list form was provided for each participant to record responses during the test. Participants wrote their responses on the response sheet provided. First, participants were tested in the unamplified condition. After unamplified testing was completed, the infrared amplification system was activated, and testing continued in the amplified condition. Listeners remained in the same seats for the amplified condition as for the unamplified condition.

To conduct amplified testing, the microphone of the infrared amplification system was placed 6 in. from the loudspeaker of the CD player. The amplification system consisted of the Audio Enhancement base station and four loudspeakers that were placed in the ceiling of each classroom. The layout of each classroom and the position of the loudspeakers in the ceiling of each classroom are shown in Figure 1. The resulting SNRs for both classrooms in the unamplified and amplified conditions are represented in Tables 1 and 2. Scoring of the NU-6 was derived by computing the percentage of words correctly recorded by each participant.

Data Analysis

A disinterested researcher (doctoral student) checked all written responses to control for data entry errors and to ensure reliability of data analysis. Incorrectly spelled responses were considered correct if their phonetic spelling matched that of the correct NU-6 word. Though a second judge was used to help catch errors, no interjudge statistics were used to demonstrate reliability because of the low occurrence (two words across all participants) of disagreement between the primary researchers and the disinterested researcher. A repeated measures analysis of variance (ANOVA) was used to analyze the mean performance data for listeners between classrooms and between amplified and nonamplified conditions. Group membership (determined by which day the listener participated) was used as a between-groups factor. Also, one-way ANOVAs were carried out for each classroom to compare mean performance by listeners across the rows of desks in the classroom.

Results

Analysis by Classroom Listening Condition

Descriptive statistics are reported in Table 3. Mean scores differed by 37% between the unamplified and amplified conditions in the poor acoustic classroom. However, mean scores in the acoustically sound classroom differed by only 11% between unamplified and amplified conditions. These data indicate that amplification resulted in improvements in word recognition for both classrooms, but the effect was more pronounced in the acoustically poorer classroom than was observed in the acoustically sound classroom (see Figure 2). A multivariate repeated measures ANOVA with classroom and amplification as within-subjects factors and group membership as the between-subjects factor revealed a significant main effect for (a) the overall difference between classrooms and whether or not amplification was present, $F(1, 51) = 294.493$, $p < .000$, (b) group membership, $F(1, 51) = 10.264$, $p < .002$, and (c) the overall listening condition by group interaction, $F(1, 51) = 7.687$, $p < .008$.[1] Post hoc Tukey pairwise comparisons showed a statistically significant improvement in the NU-6 word recognition scores of listeners in the unamplified acoustically sound classroom as compared

Table 3. Means and standard deviations of the performance of listeners with NU-6 words across each classroom and in each listening condition, reported in percentage (*N* = 53).

	Unamplified		Amplified	
	M	*SD*	*M*	*SD*
Poor acoustic classroom	44	17	81	6
Acoustically sound classroom	82	8	93	4

with the unamplified poor acoustic classroom ($p < .001$). Also, statistically significant differences were measured between the unamplified and amplified conditions in the poor acoustic classroom ($p < .001$) and between the unamplified and amplified conditions in the acoustically sound classroom ($p < .001$). It was interesting to note that the mean performance of listeners in the amplified condition in the poor acoustic classroom did not differ significantly from the performance of listeners in the unamplified condition in the acoustically sound classroom.

Within Classroom Analysis by Row

Separate univariate ANOVAs were carried out for each classroom with the presence or absence of amplification as the within-subjects variable and row as the between-subjects factor. Both univariate ANOVAs met the sphericity condition for homogeneity of variance. For the poor acoustic classroom, a significant main effect was measured for the amplification condition, $F(1, 86) = 30.16$, $p = .012$, and for the interaction between row and amplification, $F(3, 86) = 8.702$, $p < .000$. Tukey pairwise comparisons showed a significant difference between the mean performance of listeners in row 1 (front) and row 3 ($p < .001$), and also between the mean performance of listeners seated in row 2 and row 3 ($p < .019$). For the acoustically sound classroom, the same main effects were significant as were measured in the poor acoustic classroom: $F(1, 86) = 18.381$, $p < .023$, and $F(3, 86) = 5.721$, $p < .001$, for the amplified condition and the interaction between row and amplified condition, respectively. Tukey pairwise comparisons showed significant differences in the unamplified condition between the performance of listeners seated in row 4 (back of the classroom) and listeners in row 1 ($p = .015$) and row 2 ($p = .040$). A graphic representation for the results from the poor acoustic classroom by row and by amplification condition can be seen in Figure 3. The same comparisons can be observed for the acoustically sound classroom in Figure 4.

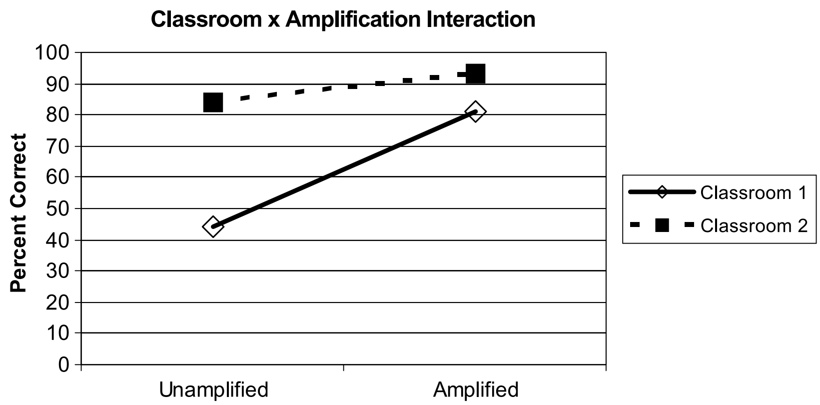
Discussion

Classroom Differences

The results of the analysis of listener performance in the four listening conditions addressed the first three research questions of the present study. The first research question was whether the speech recognition performance of college students would improve when listening in a classroom with acoustic characteristics that met the ANSI S12.60-2002 standard as compared with in a classroom not in compliance with

[1]Homogeneity of variance to meet the sphericity condition of repeated measures ANOVAs was violated for the word recognition scores data. To decrease the risk of a Type I error, a lower bound adjustment (Kirk, 1995) to the degrees of freedom was made, and the *F* and *p* values of the within-subjects factors reflect this adjustment. The violation of the sphericity condition was likely due to the lack of homogeneity in the performance of listeners in reverberation. Large variability in the speech intelligibility performance of listeners in the presence of reverberation is not a surprising finding in light of previous research with reverberation (Nabelek & Mason, 1981).

Figure 2. Mean word recognition scores in two postsecondary classrooms with different acoustics in unamplified and sound-field amplified conditions.



the standard. The significantly improved speech recognition performance of listeners (mean of 44% correct for NU-6 words) from the poor acoustic classroom unamplified to the acoustically sound classroom unamplified (mean of 82% correct for NU-6 words) is a confirmation of the benefit that can be observed for college-age listeners when the ANSI S12.60-2002 standard is met as opposed to when it is not. Considering that many college classrooms do not meet the ANSI standard (Hodgson et al., 1999; Kelly & Brown, 2002), the results of this study confirm that meeting the standard will benefit young adult listeners with normal hearing even when the acoustics of a college classroom are of good quality for speech communication. These results are limited in this study to young adult listeners' word recognition performance at low speech intensity levels. However, the results are nonetheless encouraging that improving the acoustic environment can provide significant benefits in word recognition, even for the difficult listening condition of low-intensity speech sometimes encountered by postsecondary students.

The results of the analysis also support an affirmative answer to the second research question of this study, which was whether young adult listeners show improved speech recognition performance in classrooms when a classroom amplification system is used. The change in mean speech recognition performance from the unamplified poor acoustic classroom condition to the amplified poor acoustic classroom condition was 37%. The practical significance of this difference in mean percentage correct scores is difficult to judge due to the lack of research demonstrating a relationship between performance with the NU-6 words and real-world performance. Statistically, the 37% difference in scores is roughly double the difference in word recognition scores needed to meet the 95% confidence interval for word recognition scores modeled as a binomial distribution, as calculated by Thornton and Raffin (1978). However, due to the low intensity level of the speech signal in the present study, it should not be surprising that the amplification system made a positive difference in the speech recognition scores for the listeners. These results can be considered strong evidence that, unless the acoustics of a college classroom are at least close to meeting the ANSI S12.60-2002 standard, an amplification system may be needed to help listeners in the back half of midsize to large classrooms understand the majority of the lecture that cannot be inferred from context.

The third research question asked whether the word recognition score improvement observed for each classroom when amplification was present as compared with when it was not was significantly different. The improvement in speech recognition performance with amplification in the acoustically sound classroom as compared to no amplification was 11%. This difference was statistically significant, but the practical significance of an 11% improvement is debatable. This difference in improvement was small when compared with the statistically significant improvement in the poor acoustic classroom, where the mean performance with classroom amplification across listeners was 37% (see Figures 3 and 4). A ceiling effect in the acoustically sound classroom may have influenced the amount of benefit listeners experienced from amplification. However, for a relatively quiet listening situation like that in the acoustically sound classroom, ceiling effects are both expected and desirable. In this case of quiet conditions, the quantitative improvement in benefit from classroom amplification in a classroom that met the ANSI S12.60-2002 standard was modest. Because qualitative listening issues such as ease of listening or listener fatigue were not evaluated in the present study, it is not known whether such measures would show more robust differences than the modest quantitative differences in word recognition observed for the acoustically sound classroom. The results for the poor acoustic classroom, on the other hand, show a clear quantitative benefit in speech recognition performance from classroom amplification.

Analysis by Listener Position in Each Classroom

Listeners' scores in both classrooms were analyzed according to the row in which they sat during the testing. The range of scores obtained from listeners in the poor acoustic classroom was greater in the unamplified condition (from 12% to 80%) as compared with the scores in the unamplified

Figure 3. Mean word recognition scores by row in the poor acoustic classroom (not ANSI S12.60-2002 compliant) for Northwestern University Auditory Test No. 6 (NU-6) words. Top panel shows results without amplification, and the bottom panel shows results with amplification. Error bars represent ±2 *SEM,* and the asterisk next to rows 1 and 2 indicate that their mean scores were significantly different from the mean of row 3 at the *p* < .01 level.

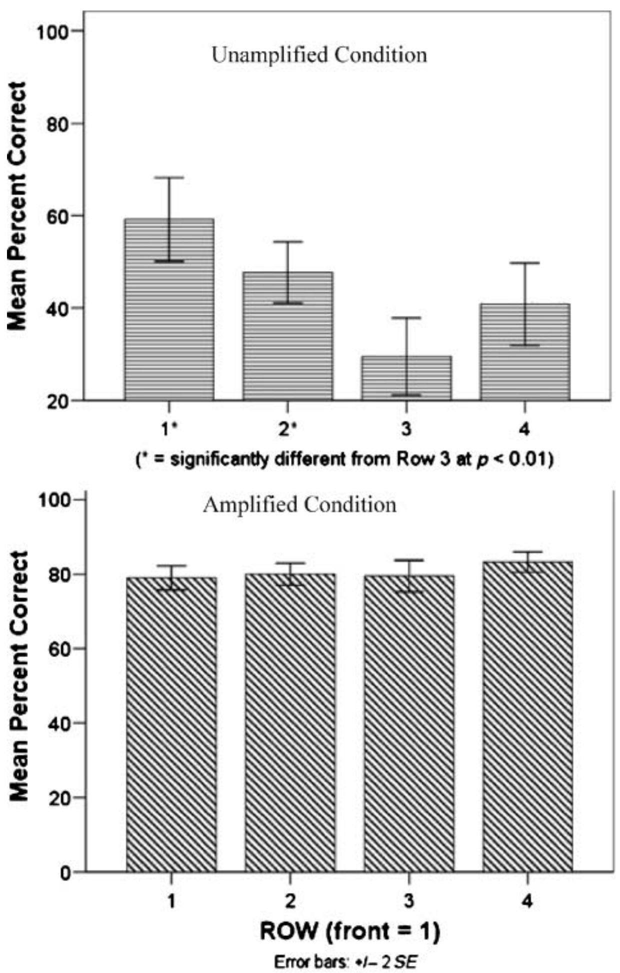
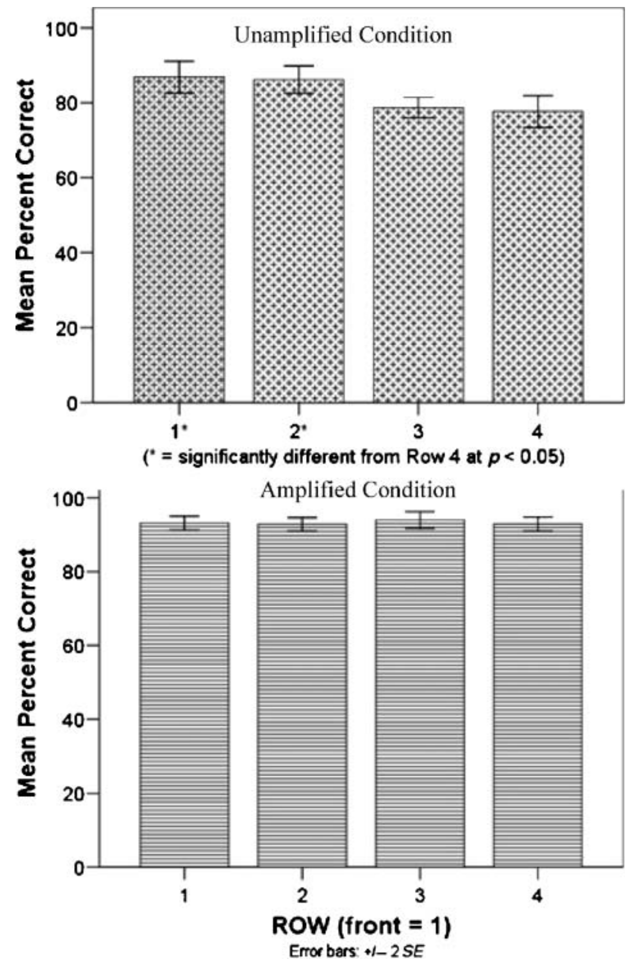


Figure 4. Mean word recognition scores by row in the acoustically sound classroom (ANSI S12.60-2002 compliant) for NU-6 words. Top panel shows results without amplification, and the bottom panel shows results with amplification. Error bars represent ±2 *SEM,* and the asterisk next to rows 1 and 2 indicate that their mean scores were significantly different from the mean of row 4 at the *p* < .05 level.



condition in the acoustically sound classroom (from 64% to 96%). With the greater range of scores for the unamplified condition of the poor acoustic classroom, it was more likely that an effect by seating position in the classroom could be observed. An ANOVA of the mean speech recognition performance by row for the poor acoustic classroom showed that the mean performance of listeners in each row differed significantly in the unamplified condition and not for the amplified condition (see Figure 3).

For the acoustically sound classroom, the ANOVA results were consistent with significant differences in mean performance across rows for the unamplified condition but not for the amplified condition (see Figure 4). The statistically significant difference in scores between row 4 (back of the classroom) and rows 1 and 2 was unexpected because the overall performance of the listeners in that classroom was relatively good and the standard deviation in scores was smaller than that observed in the poor acoustic classroom. However, the effect of distance on the intensity of the signal in the unamplified case was the likely cause of the differences in word recognition scores.

The results of the analysis by row in each classroom addressed both the fourth and fifth research questions of the study concerning whether listener performance was maintained across the classrooms with or without the use of the classroom amplification system. Speech recognition performance was maintained when the amplification system was in use in both classrooms. However, even in the classroom with acoustic properties meeting the ANSI S12.60-2002 standard, listeners in the back of both classrooms showed reduced speech recognition scores as compared with listeners in the front of the classroom (see Figures 3 and 4 to observe the differences by row and amplification condition).

The results of the present study have some important limitations that must be considered when generalizing the results to the word recognition of listeners in college classrooms. As discussed previously, the low-intensity speech presentation, while likely realistic for many college listeners seated in the rear of midsize to large college classrooms, does not represent average speech levels for college classrooms as reported by Hodgson et al. (1999) and is well below the intensity levels of elementary school teachers according to Picard and Bradley (2001). Nevertheless, the results may be interesting to college administrators who are concerned with student retention issues. Large classrooms and auditoria are often used for general education courses due to the large number of undergraduate students needing to take these courses. For those students seated in the back half of these classes, there is a high likelihood that the speech levels of the instructors of these courses is inadequate for these students to understand the speech signal without the benefit of contextual cues or the use of an amplification system. If the poor acoustic conditions interfere with the academic performance of these students, they may become discouraged due to their poor performance and leave school. While the results of the present study could support such conclusions, this discussion of classroom amplification having a significant impact on the academic performance of postsecondary students is purely conjectural until well-designed studies demonstrate such a relationship.

Conclusions

The purpose of this study was to observe changes in word recognition as a function of classroom acoustics, and with and without amplification for young adult listeners. The most important finding of the present study is that the classroom acoustics had a significant effect on word recognition scores of postsecondary students when the speech intensity in the room was relatively low. This result provides support for the idea that efforts to improve the acoustic conditions of postsecondary classrooms can significantly benefit college students, especially when listening in very poor SNR conditions in a classroom. An expected result of this study was that the young adult listeners benefited from the sound-field amplification system over listening to the low-intensity speech signal in the unamplified condition. What is more interesting is that the present study demonstrated that classroom amplification can be beneficial for college-age listeners in a classroom with reverberation levels that exceed recommended values (ANSI, 2002; ASHA, 1995).

Further study of the effects of classroom acoustics and classroom amplification with postsecondary listeners is needed to guide efforts to maximize the effectiveness of the learning environment for these listeners. Specifically, replication of the present study with a range of speech intensity levels is recommended. Also, studies of more subtle effects of classroom acoustics and classroom amplification on listening and learning over longer time periods are recommended to demonstrate that the immediate benefits observed in the present study can be maintained over time (Mendel et al., 2003).

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