



Effects of Sound Field FM Amplification on the Speech Perception of ESL Children

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Children for whom English is a second language (ESL) exhibit greater speech-perception difficulties than native English speaking children, particularly in degraded listening environments. The purpose of the current investigation was to examine the effects of sound-field FM amplification on the perceptual abilities of ESL children in a commonly-reported classroom environment. Specifically, the monosyllabic word perception of 20 ESL children were evaluated at three speaker-listener distances (6, 12, and 24 feet) in a classroom with a signal to-noise ratio (SNR) of +6 dB and a reverberation time (RT) of 0.6 seconds. Speech perception was assessed via the PBK-50s monosyllabic words, while a 12-speaker multi-talker babble served as the noise competition. Results indicated that: (1) ESL children experience significant speech-perception difficulties in the classroom, particularly when seated in the middle to rear of the room; and (2) sound-field FM amplification significantly improved the perceptual abilities of ESL children. Educational implications of these data are discussed.

Recent evidence suggests that children for whom English is a second language (ESL) often experience greater speech-perception difficulties than native English speaking children, particularly in background noise or reverberation (Crandell & Smaldino, 1995a,b; Crandell, Smaldino, & Flexer, 1995; Villareal & Crandell, 1991). Crandell and Smaldino (1995b), for example, examined the sentential-perception abilities of ESL and native English children in quiet and under noise conditions commonly reported in the classroom setting (signal-to-noise ratio (SNR) = +6, +3, 0, -3, -6 dB). Results demonstrated that although both groups obtained equivalent perception scores in quiet, the ESL children performed significantly poorer across most of the noisy listening conditions. Furthermore, performance differences in speech perception between the two groups increased as the listening environment became less favorable. While the acoustic and/or linguistic mechanism(s) for these perceptual difficulties remain uncertain, the finding that ESL children performed as well as the native English speaking children in quiet listening conditions suggests that both groups had essentially equal knowledge of the linguistic contingencies of the sentential material used in this investigation. Therefore, the reduction of speech redundancy caused by the introduction of background noise appears to adversely affect the ability of ESL children to utilize their knowledge of the syntactic, semantic, and/or lexical rules of the English language. Clearly, these findings have important educational implications for the more than two million ESL children (U.S. Department of Education, 1991) who may be routinely exposed to unfavorable listening conditions in the educa-

tional setting (Blair, 1977; Crandell & Bess, 1986, 1987; Crandell, 1991a, 1992, 1993; Crandell & Smaldino, 1992, 1995a,b; Crandell, Smaldino, & Flexer, 1995; Finitzo-Hieber, 1988; Olsen, 1981, 1988; Ross, 1978).

One possible strategy to reduce the deleterious influences of classroom noise and reverberation on speech perception is the utilization of a sound-field Frequency Modulation (FM) amplification system. With a sound-field FM amplification system, the teacher's voice is picked up via a wireless microphone located approximately 3-4 inches from the mouth. The signal is then amplified and delivered to the students through one or more strategically placed loudspeakers in the classroom. Sound field systems generally improve the classroom SNR by approximately 8-10 dB (Crandell & Smaldino, 1992, 1995a; Crandell, Smaldino, & Flexer, 1995). A review of prior research has demonstrated that the utilization of sound-field FM systems in classrooms cannot only significantly improve perceptual ability in pediatric listeners, but also academic and psychoeducational/psychosocial achievement (Berg, 1987, 1993; Crandell & Bess, 1987; Crandell & Smaldino, 1992, 1995a,b; Flexer, Millin, & Brown, 1990; Jones, Berg, & Viehweg, 1989; Ray, 1987, 1988; Ray, Sarff, & Glassford, 1984; Sarff, 1981; Sarff, Ray, & Bagwell, 1981). To date, however, the utilization of sound-field technology for ESL children has not been investigated.

The purpose of this study was to examine the effects of sound-field FM amplification on the perceptual abilities of ESL children. Specifically, the monosyllabic word perception of 20 ESL children were evaluated at three speaker-listener distances (SLDs)(6, 12, and 24 feet) in a commonly-reported classroom listening environment (SNR = +6 dB; Reverberation Time (RT) = 0.6 seconds). Speech perception was assessed via the PBK-50s monosyllabic words, while a 12-speaker multi-talker babble served as the noise competition.

Methodology

Subjects

Twenty ESL children with normal-hearing sensitivity, ranging in age from 8-10 years (mean age = 8 years, 9 months), participated in this investigation. The ESL group consisted of native Spanish speakers, all of whom began to speak English by 1.5 years of age. Each child spent at least 50% of the time speaking English as indicated by parental report.

All subjects met the following criteria:

- (1) bilateral pure-tone air-conduction thresholds no poorer than 15 dB HL from 250 to 8000 Hz in octave intervals;
- (2) normal middle ear function (± 100 mm daPa), bilaterally, as indicated by tympanometry;
- (3) speech-perception scores of 90% or better in quiet as assessed by the PBK-50 monosyllabic words at a level of 65 dB SPL;
- (4) a history of English as a second language as indicated by parental and/or teacher report;
- (5) normal growth and development as reported by the parent;
- (6) free from significant medical problems as reported by the parent.

Stimuli

Speech perception was assessed via a commercially-available audio cassette recording (Audiotec of St. Louis) of the Phonetically-Balanced Kindergarten (PBK-50s) monosyllabic words (Haskins, 1949). The PBK-50 test consists of 200 words that are separated into 4 lists. All monosyllabic words from the PBK-50s were selected from frequently used words found in the International Kindergarten Vocabulary list (Thorndike & Lorge, 1944). Previous research has demonstrated inter-list equivalency only with lists 1, 3, and 4 (Haskins, 1949). Thus, only those lists were utilized in this investigation. Three randomizations of these specific lists were available, making a total of nine word lists. The PBK-50s have been shown to be reliable for children as young as five years (see Bess, 1982 for a review).

Competing Noise

A twelve-speaker multi-talker babble from a commercially available tape supplied by Auditec was used as the noise competition. The multi-talker babble was used because it is known to have a spectrum equivalent to the long term average spectrum of speech. Moreover, this type of noise is similar to the background noises commonly encountered in every day listening environments (Aniansson, 1974; Crandell, 1991a, b). Both the PBK-50 and multi-talker babble tapes contained a 1000 Hz calibration at their onset which was equal to the long-term RMS level of the stimuli.

Classroom Environment

The experimental tapes were recorded in a classroom with commonly-reported physical dimensions (24' x 18' x 10'). A diagram of the classroom is presented in Figure 1. To simulate a traditional classroom setting, thirty table-arm student desks were

set up in six rows of five desks. In addition, there was a large teacher's desk at the front of the room with a wall-mounted blackboard positioned on the front wall approximately 2' behind

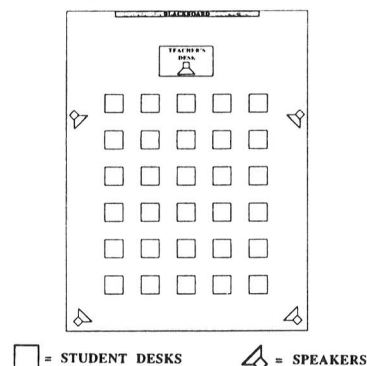


Figure 1. A diagram of the classroom used to record the experimental tapes.

the desk. The classroom contained acoustical tile ceiling and wall-to-wall carpeting. The room contained one small window (approximately 1.5 feet in width and 9 feet high) on the left side of the front wall. The RT of the classroom was 0.6 seconds. Reverberation time was determined by presenting a high intensity broadband signal (110 dB SPL) into the unoccupied room and recording decay time with a Communications Company, Model RT60B, reverberation meter. Three measures were taken at 500, 1000, and 2000 Hz and averaged to determine room reverberation. All calculations were recorded beyond the critical distance of the room to ensure that all measurements were in the reverberant sound field (Crandell & Smaldino, 1995a,b).

Recording Procedures

Experimental tapes were recorded in unamplified and amplified listening conditions. In both conditions, the PBK-50 monosyllabic words were delivered from a Sony 6" box loudspeaker which was located on the teacher's desk. The center of the speaker cone was placed at a height of 5' to simulate average teacher height. The PBK-50s words were presented through this speaker at a level of 65 dB SPL (re: 6') to simulate average conversational levels (Pearsons, Bennett, & Fidell, 1977). Due to the acoustics of the room, there was an expected decrease in the level of the PBK-50s as a function of increased distance. Specifically, sound levels were measured at 60 dB SPL and 57 dB SPL at 12' and 24', respectively.

In the amplified listening condition, speech was transduced through a Lifeline Free Field Classroom Amplification System. In this experimental condition, the microphone for the Lifeline FM transmitter was placed 4" (at 90°) from the loudspeaker that produced the PBK-50 words. Recall that this speaker presented the PBK-50s at a level of 65 dB SPL. The sound-field FM amplification system was then adjusted to produce a level of 75 dB SPL (re: 6') to simulate the average 10 dB increase in sound pressure obtained from sound field units. This increase in the primary signal resulted in sound levels of 69 dB SPL at 12' and 67 dB SPL at 24'. Speech was transduced through a four-speaker

set-up. Two speakers were located on the side walls approximately 7 feet from the front of the classroom and the remaining two speakers were placed in the two corners on the rear wall (see Figure 1). All speakers were placed at a height of approximately 5 feet (re: speaker cones). The tone control for the LifeLine unit was set in a mid position. To achieve the desired intensity levels for the unamplified and amplified listening conditions, the following substitution methodology was used. First, the loudspeaker producing the PBK-50s was positioned at a 0° azimuth to a calibrated Bruel & Kjaer, Model 2209 Type I sound-level meter. Second, the microphone of the sound level meter was positioned 6' from the loudspeaker at a level where KEMAR's head would be positioned. Third, the intensity level of the speech was adjusted to read the desired SPL via the 1000 Hz calibration tone at the onset of each cassette tape. All levels were kept constant throughout the experiment and were rechecked prior to the recording of each experimental condition.

The multi-talker babble was presented through six additional loudspeakers (Quam-Nichols #C5/B70/A) which were located in the ceiling of the classroom. These speaker locations were utilized to simulate ambient noise sources often found in a classroom. The level of the multi-talker babble was adjusted to 59 dB SPL at all speaker-listener distances; producing SNRs of +6 dB at 6'; +1 dB at 12'; and -2 dB at 24' in the unamplified condition. In the amplified condition, SNRs were +16 dB, +10 dB, and +8 dB at the three SLDs. To calibrate the noise source, a similar substitution procedure as reported above was used. In this case, however, the six ceiling speakers were activated simultaneously and adjusted to 59 dB SPL at each SLD. As with the PBK-50s, levels were kept constant throughout the experiment and rechecked prior to the recording of each experimental condition.

A Knowles Electronics Mannequin for Acoustic Research (KEMAR) mannequin, equipped with Zwislocki couplers, was used to simulate the listening conditions of a child seated in a classroom. The PBK-50s and multi-talker babble was simultaneously recorded through the KEMAR manikin at speaker-listener distances of 6, 12, and 24 feet. These SLDs were selected to approximate distances often present between teachers and pupils in a classroom setting (i.e., front, middle, and rear of a classroom). For the recording of the experimental tapes, the output from each of KEMAR's microphones was amplified and routed through an equalization filter to remove the ear-canal resonance of the KEMAR manikin. The signal was then recorded to high quality cassette tape via a cassette tape recorder. All nine lists of the PBK-50s were recorded at each SLD, making a total of 27 lists.

Listening Tasks

All speech-perception measurements were conducted in a double-walled, IAC, soundtreated room. The outputs of the two tracks of audiotape were connected separately to a two-channel mixer. Relative levels and intensities were adjusted at the mixer, amplified, and presented to subjects under TDH-49 earphones mounted in MX-41/AR supra-aural cushions. All stimuli were presented binaurally to each child at a level of 65 dB SPL. The subject's task was to repeat each sentence. The stimulus items were separated by eight seconds to allow for subject response.

The sentence lists were counterbalanced and no subject received the same list twice. Each subject was given a standard set of instructions. In addition, each child received practice trials prior to the initiation of the test. Subjects were encouraged to guess when necessary. Total test time was approximately 2 hours, which was completed in a single session. Test time included frequent breaks (approximately every 15 minutes) which were provided to assure subject attentiveness.

Results

Mean word perception scores for the ESL children for the amplified and unamplified listening conditions as a function of SLD are presented in Figure 2. The means and standard deviations for these data are presented in Table 1. Several trends from

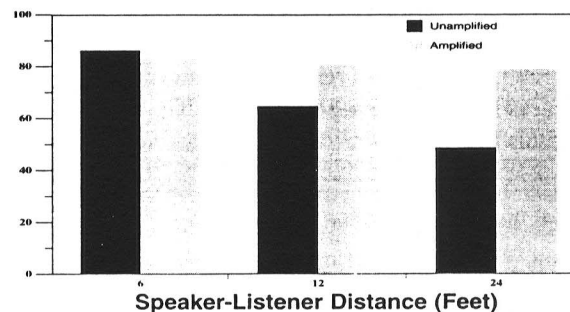


Figure 2. Mean word recognition scores, in percent correct, in amplified and unamplified listening conditions for the ESL children. Amplified listening conditions are indicated by the gray bars, while the unamplified listening conditions are indicated by the black bars.

Table 1. Mean word recognition scores (in percent correct) and standard deviations in the amplified and unamplified listening conditions for the ESL children.

SPEAKER-LISTENR DISTANCE	TEST CONDITION	
	AMPLIFIED	UNAMPLIFIED
6 FEET	84.2 (11.1)	87.1 (8.5)
12 FEET	80.6 (8.5)	64.7 (11.4)
24 FEET	79.1 (7.4)	49.2 (11.2)

these data are pertinent to this discussion. First, the ESL children experienced more speech-perception difficulties in the unaided listening condition, particular at SLDs of 12' and 24'. These results indicated that ESL children have considerably more difficulty understanding speech in the classroom setting than has customarily been suspected. Second, the speech-perception scores were significantly enhanced with the utilization of the sound field FM unit compared to the traditional, unamplified listening condition. A multi factor repeated-measures, analysis of variance (ANOVA) indicated that differences in the amplified and unamplified listening conditions were statistically significant ($F=43.32$; $df=1,5$; $p<0.0001$). Post-Hoc analyses, utilizing the Duncan Multiple Range Test (Duncan, 1955), indicated that

the subjects obtained elevated perception scores in the amplified listening conditions at SLDs of 12 and 24 feet at the $p=.01$ level. It is interesting to note that in the amplified condition, speech perception scores remained essentially constant (approximately 80-84%) across each SLD.

Discussion

The current results suggest that ESL children experience significant speech-perception difficulties, particularly when seated in the middle to rear of a classroom. Moreover, these data indicated that sound-field FM amplification can significantly augment the perceptual abilities of ESL children in the classroom setting. As stated earlier, it is uncertain why ESL children experience difficulties in speech perception, particularly in degraded listening environments (see Crandell & Smaldino, 1995a,b, for a review of hypotheses concerning perceptual difficulties in ESL listeners). It seems reasonable to speculate, however, that as the listening environment in a classroom environment becomes less favorable (thus reducing the acoustical and linguistic redundancy of the signal), ESL children are required to rely upon their knowledge of the linguistic structure of the English language to perceive the speech stimuli correctly. Since it is well recognized that linguistic proficiency in a second language rarely matches that of the native language, it is to be expected that the ambiguity in the speech signal caused by masking noise or reverberation is less well tolerated for the ESL child, resulting in considerable perceptual difficulties (Crandell & Smaldino, 1995a,b; Hamayan & Damico, 1991). Stated otherwise, ESL listeners may need to correctly perceive essentially every word in a sentence in a noisy or reverberant background for optimum communication to occur.

The perceptual difficulties exhibited by ESL children stress the need of ensuring that ESL children receive instruction within appropriate acoustical environments. One means of improving the listening environment for these children is to employ sound-field FM amplification in the classroom. Research would suggest, however, that sound-field systems are rarely, if ever, recommended for ESL populations (Crandell, Smaldino, & Flexer, 1995). Another well-recognized strategy to ensure that noise and reverberation levels are not excessive for pediatric listener is acoustical modification and/or treatment of the classroom. The reader is directed to the following sources for more detailed descriptions of acoustical modifications in the classroom (Crandell & Smaldino, 1995a; Crandell, Smaldino, & Flexer, 1995; Finitzo-Hieber, 1988; Nabelek and Nabelek, 1985; Olsen, 1988; and Ross, 1978). At present, however, acoustical standards for ESL children have not been established (Crandell & Smaldino, 1995a,b; Crandell, Smaldino, & Flexer, 1995). It has been suggested that until such standards are developed, acoustical recommendations suggested for children with hearing loss should be followed (Crandell & Smaldino, 1995a,b; Crandell, Smaldino, & Flexer, 1995). Acoustical standards for listeners with hearing impairment indicate that unoccupied classroom reverberation times should not be higher than 0.4 seconds, noise levels should not exceed 30-35 dB(A) and SNRs must surpass +15 dB for maximum communication to occur (ASHA, 1995). The use of an acoustical standard originally developed for

listeners with hearing loss seems logical as data from previous studies have indicated that adult ESL listeners obtain recognition scores similar to listeners with moderate degrees of sensorineural hearing loss, particularly in degraded listening environments (Buus, Florentine, Scharf, & Canevet, 1986; Villerreal & Crandell, 1991). Unfortunately, a review of the literature shows that the aforementioned standards are achieved infrequently in the academic setting (Bess, Sinclair, & Riggs 1984; Blair, 1977; Blair, Peterson, & Veihwig, 1985; Bradley, 1986; Crandell, 1991a; Crum & Matkin, 1976; Finitzo-Hieber, 1988; Markides, 1986; McCroskey & Devens, 1975; Paul, 1967; Pearson, Bennett, & Fidel, 1977; Ross, 1978; Ross & Giolas, 1971; Sanders, 1965).

One additional approach for reducing the detrimental effects of inappropriate classroom acoustics is to ensure that the ESL child receives instruction face-to-face and in the direct sound field of the teacher. In a classroom environment, the acoustics of a teachers voice varies as a function of SLD. At distances relatively near to the teacher, the direct sound field dominates the listening environment. In the direct sound field, sound waves are transmitted from the teacher to the child with limited modifications and distortions from room surfaces. At increased SLDs, however, the indirect sound field predominates the listening environment. In this sound field, the child is listening to a signal that not only has a less favorable SNR, but also is distorted by reverberation. The *critical distance* of the classroom is where the direct and indirect sound fields are equal in intensity. Speech-perception scores decrease until the critical distance of the room is reached (Crandell & Bess, 1986, Crandell, 1991a; Crandell & Smaldino, 1995a,b; Nabelek & Nabelek, 1985). Beyond the critical distance, perception ability tends to remain essentially constant. These findings suggest that speech perception can only be improved by decreasing the SLD within the critical distance of the room. Thus, restructuring classroom activities in relation to SLD may be highly beneficial to ESL children. Specifically, small group instruction should be recommended over more traditional classroom settings. Close proximity to the teacher will also assist the ESL listener in optimizing speech reading ability. It must be noted, however, the critical distance occurs at SLDs of approximately 3-6 feet from the teacher in classroom settings. Thus, preferential seating may not place the ESL child within the critical distance and therefore not provide an appropriate listening environment. In many cases, few children who receive preferential seating are actually within the critical distance of the classroom throughout the majority of the academic day due to the teacher's movements in their classrooms (Crandell, Smaldino, & Flexer, 1995).

In conclusion, this discussion has addressed several issues concerning the perceptual abilities of ESL children in the educational setting. First, commonly-reported classroom acoustics have a detrimental effect on the speech perception of ESL children and therefore may compromise a student's academic achievement. Second, one procedure to reduce the effects of inappropriate classroom acoustics is the application of sound field FM amplification. Specifically, this investigation noted that the speech-perception abilities of ESL children were significantly improved with the utilization of such systems. Finally, additional procedures such as acoustical modification of the classroom and reducing SLD can be implemented to improve the listening environment for the ESL child in the academic setting.

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