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Children With Developmental Disabilities: The Effect of Sound Field Amplification on Word Identification

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Because teachers manage and instruct students through verbal communication, it would seem logical that improvement of pupil's abilities to detect and attend to the teacher's speech could improve pupil performance. Using sound field amplification which increased the intensity of the teacher's voice by 10 dB, nine children who attended a primary-level class for children with developmental disabilities, made significantly fewer errors on a word identification task than they made without amplification. Observation showed the children to be more relaxed and to respond more quickly in the amplified condition.

KEY WORDS: sound field amplification, developmentally handicapped, classroom acoustics

Most classroom management and instruction is oral, with the underlying assumption that pupils can and must detect and attend to the teacher's speech. In fact, Elliot, Hammer, and Scholl (1989) found that auditory discrimination has primary importance for the development of basic competencies that underlie school success. It would therefore seem logical that improvement of pupils' abilities to detect and attend to the teacher's speech could enhance pupil performance.

A major problem in a typical classroom is that ambient (background) noise levels tend to be similar throughout the room, but speech levels diminish as the distance between teacher and pupil increases. In some locations, therefore, the signal-to-noise ratio (S/N, the ratio in dB of the speech signal level to the ambient noise level) may be so poor that critical components of the teacher's speech drop below the ambient level. This effect is especially detrimental to speech understanding if the higher speech frequencies, which contain a disproportionately great amount of information necessary for speech understanding (Ling, 1976), drop to a level near to or below the ambient noise. When this happens, both the audibility and intelligibility of speech are dramatically reduced.

Technology has provided a way to counteract unfavorable listening conditions and to improve the S/N. Historically, personal FM units have been the means of improving the S/N for the individual student who is wearing a radio receiver. Recently, sound field amplification has been proposed as a means of amplifying the teacher's speech for the benefit of the entire classroom, whether or not pupils have hearing losses (Berg, 1987). Through the use of 2 or 3 loudspeakers mounted on the wall or ceiling, the teacher's voice, transmitted via a wireless FM unit, is amplified evenly throughout the room, no matter where the teacher or pupils are located.

Although data are scarce, evidence is accumulating that pupil performance improves significantly in typical classrooms with sound field amplification (Flexer, 1989). Both improvement in achievement test scores and reduction in referrals for special services have been reported when amplifiers were used, particularly in normal kindergarten classrooms (Ray, Sarff, & Glassford, 1984).

Unlike typical classrooms where the primary mode of instruction is through large group presentation of lesson plans, developmentally disabled (and all of special education) class sizes are generally small (Mandell & Gold, 1984). No study has attempted to determine whether sound field amplification in classrooms for developmentally disabled children can generate improvement in student performance comparable to that which has been obtained using amplification in ordinary classrooms.

Attention to and concentration on tasks, which are basic requirements for learning, are usually deficient in special education populations (Safford, 1989). Attentional diffi-

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culties have also been reported in children with minimal hearing loss, which is a common disability in school-age children, especially learning-disabled children (Bennet, Ruuska, & Sherman, 1980). In fact, Dahle and McCollister (1986), Fulton and Lloyd (1968), and Ray et al. (1984) reported that there is a greater incidence of conductive hearing impairment among children who experience disabilities than would be expected in a regular classroom population.

Poor listening environments also negatively affect how well children attend to the teacher (Berg, 1986). Classrooms are noisy places; scuffling in the room, hallway noise, the buzz of fluorescent lights, and outside traffic are all acoustic distractions. In addition, teachers and students do not remain in fixed positions throughout the day. Thus, pupils receive speech signals of varying intensities. Listening problems caused by poor acoustics and teacher movement are compounded in children with developmental disabilities because they often have a higher than average incidence of mild, fluctuating hearing losses which can further reduce learning effectiveness (Reichman & Healey, 1983; Silva, Chalmers, & Stewart, 1986).

The purposes of this study were (a) to determine the acoustic effects of sound field amplification on the relative S/N and uniformity of overall SPL in a typical classroom, and (b) to determine the effect of sound field amplification on word identification scores in a group of students with developmental disabilities.

METHOD

Subjects

The subjects were nine students, (eight males and one female) enrolled in a developmentally handicapped primary-level class. The children were placed in this class by school personnel who used the criterion of an average IQ score of 80 or below as derived from standardized evaluative tests. The students' ages ranged from 4:5 to 6:10, with a mean age of 6:0. Additional disabilities included: attention deficit disorders, Apert's Syndrome, and seizure disorders. Parent reports and school files revealed that six of the nine children had known histories of fluctuating hearing loss, varying from normal to moderate severity. None, however, wore hearing aids.

Hearing Tests

Within 2 weeks preceding the experimental procedures, all nine children had audiometric evaluations. Seven of the nine students had thorough hearing testing in an audiometric sound room, including detailed case history, pure tone air and bone conduction thresholds, acoustic immittance measures, speech recognition threshold testing, and word identification testing, to determine the past and current status of hearing sensitivity. The room met ANSI S3.1-1977 for audiometric testing. The audiometer was calibrated to ANSI S3.6-1969 and the immittance meter was calibrated according to the manufacturer's instructions.

Two of the children were unable to participate in complete testing due to transportation difficulties, but pure-tone air conduction thresholds and acoustic immittance measures were obtained for them in a quiet room at the school, using a portable audiometer and impedance bridge. While the audiometer and impedance bridge were calibrated by the standards specified above, the ambient noise in the quiet room may have produced slight threshold shifts for these two subjects. However, since subject 9, who was one of these two children, showed hearing well within normal limits, the room was assumed to be adequate for pure tone testing. Results of pure-tone air conduction testing and tympanometric pressure readings are presented in Table 1. Note that only one child, subject 9, had normal hearing using a criterion for threshold of 15 dB HL (Northern & Downs, 1984, Ross & Giolas, 1978) or better, and normal criteria for immittance results [−200 tympanometric pressure], (ASHA, 1979; Bess, 1980). The six children with persistent hearing losses had been repeatedly referred by the school for medical treatment, but had not been educationally managed prior to the introduction of sound field equipment by the school's speech-language pathologist.

Classroom

The classroom was 35 feet long and 27 feet wide. The ceiling was not acoustically treated, but the floor was carpeted. The walls were of brick block, with chalkboards and bulletin boards on the full length of one long and one short wall. The other two walls were lined with counters and shelves, with two windows in one of the short walls.

Sound Field Equipment

The amplification device was a monophonic SRT-100 Classroom Acoustic Sound Field System, consisting of an FM wireless transmitter, a receiver, a 35-watt public address amplifier with an equalizer network, and two loudspeakers connected in phase. A small electret condenser microphone, attached by a clip to the teacher's lapel, was wired to a transmitter worn at her waist. The receiver, mounted on a corner shelf, included an output level control and a telescoping receiving antenna. Loudspeaker output could be adjusted to improve the speech signal by altering the system frequency response using the equalizer network with bands centered at 150 Hz, 1,000 Hz and 6,000 Hz. Each loudspeaker had two, 10 inch woofers and a small horn tweeter.

The loudspeakers were mounted on shelves 6 feet from the floor on one long wall. They were 12 feet apart and tilted downward two inches so that the speaker axes were directed at the opposite wall about three feet from the floor. They were also angled slightly inward to produce reinforcement in the center of the room where the high

TABLE 1. Subject audiograms and tympanic pressure.

			Air Conduction Thresholds in dB HL					
Subject	*Ear*	*Tymp. Press.*	*250*	*500*	*1,000*	*2,000*	*4,000*	*8,000*
1	RE	−150	25	20	15	10	15	30
	LE	−150	20	25	20	10	15	20
2	RE	−150	30	25	20	5	10	15
	LE	−100	20	20	15	10	15	5
3*	RE	Flat	CNT	CNT	10	CNT	5	CNT
	LE	Flat	CNT	CNT	15	CNT	10	CNT
4	RE	−100	10	10	5	0	0	5
	LE	−400	15	20	25	10	10	35
5	RE	−100	25	25	15	5	10	20
	LE	−150	40	30	20	15	15	35
6	RE	−250	10	15	20	15	5	5
	LE	−250	20	25	10	0	10	10
7	RE	Flat	25	15	15	5	15	5
	LE	Flat	40	30	25	30	35	40
8	RE	−150	20	25	25	5	5	0
	LE	Flat	20	30	40	35	20	55
9	RE	0	5	0	0	0	0	0
	LE	0	0	5	0	0	0	0

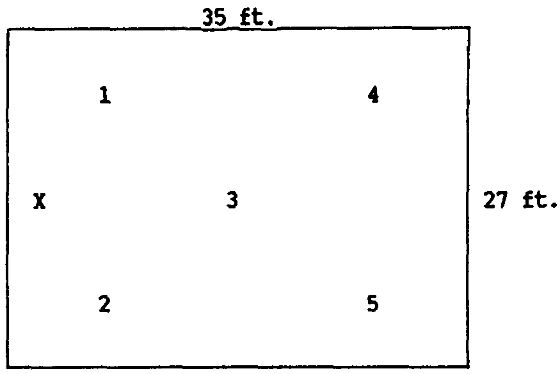
*Subject 3 was medicated for a seizure disorder and could not complete testing in the time allotted.

frequency side radiation of the speakers was relatively weak.

The sound field amplification system was adjusted to counteract weak teacher voice levels and ambient noise interference by (a) increasing the overall speech level, (b) substantially improving S/N level, (c) producing a nearly uniform speech level in the room, unaffected by teacher position, and (d) adjusting the amplifier frequency response to emphasize the higher speech frequencies. In order to achieve these increases in both overall and relative high frequency speech levels without danger of feedback, the 150 Hz band had to be maximally attenuated (6 dB), the 1,000 Hz band was set to the neutral position (marked 0), and the 6,000 Hz band was set at +6 dB. The final volume control position was at marking 10, which was the mid rotation position of the amplifier volume control.

The equipment used to monitor the amplifier system adjustments and to evaluate the effect of the adjustments was a tripod mounted B&K 2209 Precision Sound Level Meter with an omnidirectional, field microphone (B&K 4165). Although this microphone was designed for sound field measurement and is claimed to produce errors no larger than 1 dB regardless of orientation, to assure minimum error, it was positioned on a gooseneck and its axis always pointed toward the teacher at a constant elevation approximating the average ear level of seated students for all measurements. Measures were made of both the ambient levels and variations in teacher speech intensity at five evenly spaced positions around the classroom (see Figure 1). Except for the teacher and two experimenters, the room was empty during these measurements.

It would have been desirable to include measurements of noises made with children in the classroom because these noises are doubtless a source of distraction and



X = Teacher position

1,2,3,4 and 5 = Listener Positions,

Positions 1,2,4,5 are 7 feet from walls

Position 3 is in exact center of room

FIGURE 1. Teacher and listening positions in classroom.

interference with speech comprehension. However, the intermittent and often long-term intervals between sudden and highly variable impact noises or scuffling noises made it impossible to deal with them statistically in any meaningful way. It was assumed, however, that any beneficial effect found in the relatively controlled conditions under which the children were tested would also prevail under noisier, less controlled conditions.

The teacher stood about 6 feet from the middle of one of the short walls (see position X, Figure 1). Using spondees to minimize peak sound level fluctuations, she spoke at typical classroom teaching intensity, first without amplification and then with the amplifier functioning. A-weighted, overall sound level measures as well as low

(250 Hz) and high frequency (2,000 Hz) octave band levels were measured, and are presented in Table 2. The teacher's voice was monitored with the B&K sound level meter at a fixed distance of 6 ft, to assure that the peak voice intensities did not change substantially during the course of the measurement procedure. The SLM used for teacher monitoring was a B&K model 2205 with a 4145, 1″ field microphone with random incidence corrector. After modification by the manufacturer, this meter is identical to the B&K model 2209 used for measuring levels at the various room positions. Twenty five peaks were averaged for each listening position.

A primary objective was to obtain an amplified level which was as nearly constant as possible at all room positions regardless of the teacher's location. After completing the fixed measures, she moved around the room and it was determined that the amplified levels remained virtually unchanged across positions. It should be noted that this particular sound system required extensive manipulation and monitoring. It was not "user friendly."

Procedures

In order to evaluate the immediate effect of enhancing the intelligibility of the teacher's speech using sound field amplification, group administration of The Word Intelligibility by Picture Identification Test (WIPI, 25 words) was performed (Ross & Lerman, 1971). The WIPI is a picture pointing task suitable for preschool and kindergarten children. Prior to testing, the classroom teacher reviewed the WIPI to assure that all of the words were familiar to the children.

The stimulus words were presented live voice by the teacher, using "normal" vocal effort and intensity. The decision to use live voice was based on preliminary measures made with the teacher's voice and the voice of one of the experimenters presented through a single loudspeaker in a fixed position. Because the loudspeaker's transmission surface is so much larger than the point source represented by the teacher's mouth and because its motion is on a single axis, it was found that the distribution of sound from the loudspeaker was substantially different from the pattern generated by live talkers.

This difference was important. Although the loudspeaker dispersed low frequencies much like those generated by the teacher and the experimenter, the higher speech frequencies fell off rapidly on either side of the loudspeaker axis, compared to much stronger side distribution of high frequencies generated by the teacher and experimenter. This lack of lateral transmission of high frequencies is a common characteristic of loudspeakers. In order, therefore, to replicate the real teaching situation as much as possible, live voice was used.

The teacher's voice was monitored by SLM in the same manner previously described for room position measurements. Her level was found to remain consistent throughout list presentations. This is not to say, however, that the levels of all words were identical, since individual words generate somewhat different levels when a talker maintains constant vocal effort. The average of the teacher's voice peaks varied little, however, from the beginning to the end of the session. The use of constant vocal effort rather than a constant word presentation level is a common feature of discrimination testing.

An unamplified word list was first presented to half of the class; then a different amplified list was presented. For the second half of the class, the order was reversed and they heard an amplified list first, then an unamplified list. Different, but essentially equivalent word lists were used for all presentations to avoid any learning due to list familiarity from one presentation to the next.

Each child sat at a separate table with an adult who scored responses from the child's own copy of WIPI picture plates. The four tables were positioned in a line across the center of the room, where the unamplified S/N was found to be relatively poor. Seating of the second group was identical to that of the first group, except that one table was added for the fifth child. This positioning was designed to minimize the effect of varying distances from the teacher on subject performance. In addition, the adults made sure that the children remained positioned

TABLE 2. A-Weighted and filtered amplified and unamplified teacher speech levels and ambient noise levels in five classroom listening positions.

	A-Weighted Levels in dBA			*Filtered Levels in dB SPL*			
		Teacher Voice				*Teacher Voice*	
Room Position	*Ambient Noise*	*Unamp*	*Amp*	*Filter Freq Hz*	*Ambient Noise*	*Unamp*	*Amp*
1	42	51	58	250	44	48	51
				2000	37	46	52
2	43	54	62	250	46	50	55
				2000	39	47	54
3	43	46	59	250	45	49	53
				2000	37	42	54
4	43	52	61	250	43	46	54
				2000	39	46	52
5	42	48	59	250	44	46	54
				2000	38	44	56

during the experimental testing so that they could not see the teacher or other children.

RESULTS

The A-weighted ambient noise levels, as expected, were consistent at all measurement positions, varying only slightly between 42 dB and 43 dB (See Table 2). A-weighted unamplified voice levels, however, were clearly uneven across positions. In position 3 (the center of the room) the S/N was only 3 dB but at position 2, close to the teacher, it was 11 dB. Amplification increased the overall speech level by an average of 10 dB across positions, and increased the S/N from an average of 7 dB to no less than 16 dB at any position. Variations in voice level in the amplified condition were reduced to only 4 dB across positions. Note that, as determined by averaging across conditions, the system boosted the 250 Hz octave band level from 48 dB to 54 dB, an average increase of 6 dB, and improved the 2,000 Hz octave band level from 45 to 54 dB, an increase of 9 dB, thus emphasizing the high speech frequencies by 3 dB, relative to the low frequencies.

The number of errors under each listening condition are shown in Table 3. A paired comparisons test revealed significant group improvement under amplification [$t(8) = 2.75$; $p = .0125$]. Seven of the 9 students showed a reduction in errors under amplification ranging from 1 to 8 words. One student showed no performance change and another had one less error in the unamplified condition.

The average improvement of the group was 2.4 words per student. Stated differently, the students made almost three times as many errors in the unamplified condition than they did under amplification. Theoretically, the improvement could be even greater, since although all students made errors without amplification, under amplification four made none. This ceiling effect suggests that a more difficult task could have produced even greater improvement.

It is risky, of course, to put too much emphasis on an improvement of one word on a 25 word identification task (Thornton & Raffin, 1978). The greatest improvement was found for subjects, 1, 3, 5 and 8 (Table 3). The mean pure tone averages (PTA) for these four subjects was approximately 6 dB poorer in the better ear than the PTAs for the rest of the subjects, suggesting that the benefits of sound field amplification improve substantially as hearing worsens. On the other hand, when individual thresholds are examined, cases can be found where some pupils showing minimal improvement have PTAs equal to or little different from the average of pupils showing substantial improvement. Another possible interpretation is that the experimental procedure identified not only pupils whose scores improved due to compensation for marginal hearing loss, but also those for whom sound field amplification reduced the effects of attentional deficits, distractibility or other behavioral features associated with developmentally handicapping conditions.

TABLE 3. Number of errors made on the WIPI Test by each subject in amplified and unamplified conditions.

Subject	*Errors Unamplified*	*Errors Amplified*
1	4	1
2	1	0
3	10	6
4	1	0
5	8	0
6	2	3
7	3	2
8	5	0
9	1	1
Total errors	35	13
Mean errors	3.9	1.4

Informal observations revealed that the children appeared more relaxed in the amplified condition. During the unamplified condition many asked "What" after words were presented and four students tried several times to look at the teacher or at the responses of other children. No one asked "what" or tried to peek when the teacher used the sound field equipment. In general, all children appeared more hesitant and took longer to respond during the unamplified session. Even those children whose scores were not much different across conditions, responded more quickly under amplification. All subjects reported that they liked the "microphone."

DISCUSSION

The purpose of this study was to determine if sound field amplification could reduce the effects of distractibility, minimal hearing loss, and typical classroom noise in a class for students with developmental disabilities.

Several important conclusions can be drawn from this study. First, only one child had normal hearing and normal middle ear function when tested. The incidence of mild hearing loss among special populations may be underestimated. Second, even though none of the children in this study were identified as "hearing handicapped" according to generally accepted screening criteria and medical examination, their "mild" hearing losses could potentially interfere with classroom performance.

Third, sound field amplification, properly used, does overcome the effects of ambient noise and distance from the speaker, providing an improved and consistent S/N ratio throughout the classroom. During informal observation it was clearly evident that the children were more relaxed, responded more quickly, and made more accurate responses when the teacher's speech was amplified.

It should be noted that some sound field systems are easier to operate than others. The system used in this study was difficult to manipulate because adjustment controls were not calibrated so that precise changes could be made. It was necessary, therefore, to make adjustments and then determine whether desired levels were achieved by making further meter measurements. Logistics of equipment use and maintenance should be carefully evaluated before purchase.

Finally, it should not be surprising that children perform better when they hear better. Academic achievement is largely predicated on the pupil's ability to discriminate word/sound differences (Elliott et al., 1989). Because teacher and pupil movement, poor classroom acoustics, hearing loss, and inattention interfere with a child's ability to detect such differences, any strategy that could counteract this interference would be helpful. Sound field amplification makes improved use of the critically important auditory modality, and thus ought to be considered as an educational tool in special classes as well as in regular classes.

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