Preserving General Classroom Listening While Enhancing the Signal From the Teacher: Evaluation of Two Methods

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Technology for delivering an enhanced signal from the classroom teacher via FM transmission is reviewed. Two of the newest technologies, variable M/T gain relationship and voice-activated teacher microphones, were evaluated. To evaluate performance when using the T-only and the M/T hearing aid setting with variable relative gain, data were collected from one 11-year-old subject. Results indicated that the environmental microphone gain required to maintain teacher understanding would eliminate hearing any classroom signals. Next, two voice-activated FM systems were evaluated using a simulated classroom set-up. The time that is required for the environmental microphone on a voice-activated FM system to produce full output as measured in a listener's ear, as a function of FM microphone input deactivation, was quantified. The results indicated that a delay between 1.4-1.8 s (depending on the system used) exists before the environmental microphone produces its full output, whether preceded by FM microphone activation or silence. Results of both evaluations are discussed in terms of the impact they might have on recommendations made by audiologists who work with students who are hearing impaired.

INTRODUCTION

The child who is moderately-to-severely hearing impaired is often faced with less than ideal listening environments in a typical classroom (Crandell & Smaldino, 1995). The child communicates with a teacher and other children in an auditory-verbal environment. Berg (1987) reports that children spend 45% of the school

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day engaged in listening activities. According to investigators, classroom listening environments for children who are normal hearing should consist of a signal-to-noise ratio (SNR) no worse than +15 dB (American Speech-Language-Hearing Association, 1995; Crandell & Bess, 1987; Elliott, 1979, 1982; Finitzo-Hieber & Tillman, 1978; Nabelek & Robinson, 1982), with the noise level in the unoccupied classroom not exceeding 35 dB (A) (Bess & McConnell, 1981; Crandell, 1991; Crandell & Bess, 1987; Finitzo, 1988). Reverberation time should be 0.4 s or less (American Speech-Language-Hearing Association, 1995; Crandell & Bess, 1986, 1987; Crum, 1974; Finitzo-Hieber & Tillman, 1978). Unfortunately, classrooms often exhibit noise levels from 41-51 dB (A) (Bess, Sinclair, & Riggs, 1984; Crandell, 1991) which preclude SNRs of +15 dB even for students in the front row. Typical SNRs range from +5 to -7 dB (Blair, 1977; Finitzo-Hieber & Tillman, 1978; Paul, 1967; Sanders, 1965) and reverberation times from 0.4 to 1.2 s (Crandell, 1991; Finitzo, 1988; Nabelek & Pickett, 1974).

The need of the mainstreamed child with hearing impairment to hear the primary classroom signal (the teacher) has long been recognized by audiologists. The recommendation of a personal FM system for the student who wears a hearing aid is a widely accepted intervention (Blair, 1977; Hawkins, 1984; Ross & Giolas, 1971; Ross, Giolas, & Carver, 1973). These systems generally consist of a teacher's microphone and FM transmitter. The student has a receiver pack and the signal is coupled to the ears via a neckloop and telecoil pickup in the hearing aid, direct audio input, or earphones. During use, the primary signal to reach the student is the signal closest to the transmitter microphone. The hearing aid microphone is inactive. This type of system enhances the SNR provided to the student. The noise (air conditioners, chairs and paper moving, children talking, etc.) of the classroom is greatly reduced because of the proximity of the primary signal to the microphone.

Despite improved SNRs, Ross (1981) stated that the hearing aid microphone must be activated while using the FM system in order to facilitate self-monitoring and child-to-child communication. Since Ross' recommendation, only three studies have investigated the impact of adding an environmental microphone input (on the receiver or on the actual hearing aid) to the direct signal from the teacher (Freeman, Sinclair, & Riggs, 1980; Hawkins, 1984; Van Tasell & Landin, 1980).

Freeman et al. (1980) compared the electroacoustic performance of auditory trainers set to FM-only and EM-only (environmental microphone) responses. They found that the average gain was greater in the EM-only mode. This investigation did not examine the overall output produced by either the FM or EM modes and did not examine the use of FM and EM modes simultaneously. Van Tasell and Landin (1980) also found that the signal transduced by the environmental microphone was more intense than the signal transduced by the teacher microphone on several FM systems. The authors questioned whether this would impact the SNR benefits of using an FM system when the FM and EM modes were used simultaneously.

Hawkins (1984) investigated classroom listening with hearing aids alone, hearing aids and FM systems as a function of coupling strategy and microphone type, and FM systems with active environmental microphones. In addition, he examined all of these as a function of monaural versus binaural hearing. His data revealed that the FM plus hearing aid environmental microphone setting showed no SNR advantage over the hearing aids-only condition. In other words, the students lost the entire SNR advantage originally provided by the FM system (between 11.8 and 18.4 dB). Hawkins (1984) concluded that:

> when the environmental microphone is activated, the S/N advantage of an FM system is reduced substantially. Environmental microphones should be turned on only when absolutely necessary and then consideration should be given to reducing the gain for this portion of the signal. (p. 417)

Recent advances in hearing aids and FM systems have been in direct response to the belief that self-monitoring and child-to-child communication in the classroom are important and that previous technology, as demonstrated by Hawkins (1984), has not been adequate for these purposes.

Table 1 contains a listing of the numerous FM coupling options that have been suggested to accommodate both teacher and classroom communication. Currently the audiologist has little data to assist in the selection of a coupling/microphone arrangement for a particular child.

Options 1-4 represent the traditional coupling method used when only the teacher input was considered important. The only difference among these entries is the coupling method (direct audio input, neckloop to telecoil, earphones, or behind-the-ear with built-in FM receiver). Entries 5-7 and 11-13 were the first-generation solution proposed for accessing classroom communication. The difference between the two sets of entries consists of environmental microphone placement (on the FM receiver or at the hearing aid microphone). This was the type of arrangement investigated by Hawkins (1984) and found to be unsatisfactory in maintaining the enhanced teacher signal.

In response to poor reports regarding the use of environmental microphones with FM systems (Freeman et al., 1980; Hawkins, 1984; Van Tasell & Landin, 1980), manufacturers introduced environmental microphones with separate volume controls or systems where the FM level could be increased over the microphone response via a potentiometer for self-contained FM units. This solution is represented by 8-10 in Table 1. The parallel solution for FM systems coupled to hearing aids is represented by 14-16 in Table 1. The relative gain of the telecoil output and microphone output is chosen via a potentiometer (M/T) on the hearing aid. Although this is a fairly recent option to be added to hearing aids, Hawkins (1984) actually suggested reducing the hearing aid volume control so that the environmental microphone output would be reduced. The functional im-

Table 1

Coupling Options and Corresponding Microphone Set-Ups Used to Facilitate Teacher and Child-to-Child Communication

	Coupling option	Microphone(s) activated	Typical hearing aid setting abbreviation
1	Receiver to binaural DAI	Teacher mic only (VC on receiver and/or hearing aid)	M or T
2	Receiver to neckloop to binaural telecoil	Teacher mic only (VC on receiver and/or hearing aid)	T
3	Receiver to earphones	Teacher mic only (VC on receiver and/or hearing aid)	N/A
4	Binaural BTE built-in FM	Teacher mic only (VC on receiver and/or hearing aid)	F
5	Receiver to binaural DAI	Teacher mic and constant environmental mic on receiver (w/o VC)	M or T
6	Receiver to neckloop to binaural telecoil	Teacher mic and constant environmental mic on receiver (w/o VC)	T
7	Receiver to binaural earphones	Teacher mic and constant environmental mic on receiver (w/o VC)	N/A
8	Receiver to binaural DAI	Teacher mic and environmental mic on receiver (VC or FM level potentiometer)	M or T
9	Receiver to neckloop to binaural telecoil	Teacher mic and environmental mic on receiver (VC or FM level potentiometer)	T
10	Receiver to binaural earphones	Teacher mic and environmental mic on receiver (VC or FM level potentiometer)	N/A
11	Receiver to binaural DAI	Teacher mic and hearing aid mic (relative gain pre set)	M/T or M/A
12	Receiver to neckloop to binaural telecoil	Teacher mic and hearing aid mic (relative gain pre set)	M/T
13	Binaural BTE built-in FM	Teacher mic and hearing aid mic (relative gain pre set)	B or M/F

Continued on next page

Table 1 *Continued*

	Coupling option	Microphone(s) activated	Typical hearing aid setting abbreviation
14	Receiver to binaural DAI	Teacher mic and hearing aid mic (choose relative gain)	M/T or M/A
15	Receiver to neckloop to binaural telecoil	Teacher mic and hearing aid mic (choose relative gain)	M/T
16	Binaural BTE built-in FM	Teacher mic and hearing aid mic (choose relative gain)	B or M/F
17	Receiver to monaural DAI	Teacher mic to monaural telecoil, hearing aid mic on opposite ear	M or T and M
18	Receiver to neckloop to monaural telecoil	Teacher mic to monaural telecoil, hearing aid mic on opposite ear	T and M
19	Receiver to monaural earphone	Teacher mic to monaural earphone, hearing aid mic on opposite ear	N/A and M
20	Monaural BTE built-in FM	Teacher mic to monaural BTE built-in FM, hearing aid mic on opposite ear	F and M
21	Receiver to binaural DAI	Voice-activated teacher mic and environmental mic on receiver (w/o VC)	M or T
22	Receiver to neckloop to binaural telecoil	Voice-activated teacher mic and environmental mic on receiver (w/o VC)	T
23	Receiver to binaural earphones	Voice-activated teacher mic and environmental mic on receiver (w/o VC)	N/A
24	Receiver to binaural DAI	Voice-activated teacher mic and environmental mic on receiver (with VC)	M or T
25	Receiver to neckloop to binaural telecoil	Voice-activated teacher mic and environmental mic on receiver (with VC)	T
26	Receiver to binaural earphones	Voice-activated teacher mic and environmental mic on receiver (with VC)	N/A

Note. BTE = behind the ear. DAI = direct audio input. VC = volume control. M = microphone. T = telecoil. N/A = non applicable. FM = frequency modulated.

pact of manipulating the environmental (hearing aid) microphone output relative to the FM microphone output has not been systematically investigated.

An alternate solution to the variable FM microphone and environmental microphone output relationship has been introduced recently. This solution is described in 21-26 in Table 1. Two systems that use voice-activated microphone technology (Mikroport by Sennheiser and Smart-Mic by Comtek) have been introduced into the educational market. The premise of these systems is that to maintain the benefit of the FM input to the listener, one would have to reduce the microphone output to such a level that it would become useless. Theoretically, voice-activated technology allows turn taking of the signals without reducing either one. Whenever the teacher's microphone is activated, that is the only signal that the child hears. When the teacher's microphone is no longer receiving a signal, the environmental microphone is engaged. The author is unaware of any published data defining the parameters of the voice-activated systems or presenting data related to classroom performance.

The purpose of the two evaluations described in this paper was to evaluate the latest proposed solutions to self-monitoring and child-to-child communication using FM systems. The first case study evaluates the speech recognition in a classroom of one student using an FM system with a variable environmental microphone output contained on the hearing aid (item 15 from Table 1). The second evaluation attempts to define some of the physical properties of using a voice-activated system (items 22 and 25 from Table 1).

EVALUATION OF FM WITH AND WITHOUT THE ENVIRONMENTAL MICROPHONE

The subject was an 11-year-old male who had a congenital bilateral moderate-to-severe sensorineural hearing loss (see Figure 1 for audiometric data) with 92% word recognition score (NU-6 half-list) in quiet, binaurally. The subject normally wears BTE hearing aids in the classroom and at home. His hearing aids are single channel, single memory, AGC instruments with a Class D amplifier/receiver and compression output limiting. He is mainstreamed into a regular education 5th-grade classroom and communicates verbally. He has used an FM system coupled to his telecoil via a neckloop for 3 academic years.

He was seen for a speech/language evaluation because of his parents' concerns about articulation problems. A battery of speech/language tests (including Peabody Picture Vocabulary Test – Revised, Test of Problem Solving, Test of Language Development, and Clinical Evaluation of Language Function) revealed age appropriate results across tests. The final speech/language report indicated that his articulation difficulties did not interfere with intelligibility. He is seen in the schools for articulation therapy and he is monitored by an educational audiologist for any classroom listening problems.

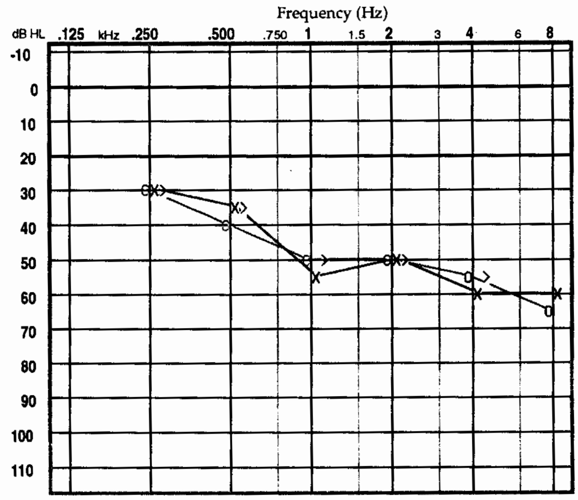

Figure 1. Audiometric data for the subject participating in the evaluation of FM with and without the environmental microphone.

Electroacoustic Assessment of the Amplification Systems

Hearing aid settings. For the purpose of testing, binaural hearing aids equipped with M (omnidirectional), T, and M/T settings were used by the subject. Although these were not the subject's personal hearing aids, they incorporated the identical circuitry and processing components (described above). The subject's personal hearing aids could not be used because they did not have the M/T option. The subject's personal hearing aids were assessed electroacoustically at use gain (determined by comfortable loudness judgments to conversational speech) with the earmold attached in the hearing aid test box (Virtual Model 340). The laboratory hearing aids attached to the subject's earmolds were then adjusted to match the 2 cm^3 response of the personal hearing aid/earmold combination. The response was made identical in order to avoid confounding the results of this investigation with the impact of a new hearing aid response. The volume control wheel setting on the laboratory hearing aids required to match the student's individual hearing aid responses was considered the use gain setting (volume control = 3) for the rest of the experiment.

FM system settings. The Williams Sound Personal FM system was used in this investigation. The volume control for the FM receiver was set in the following manner (Hawkins, 1984) and remained in the same position throughout the investigation. A speech-weighted composite noise was presented from a 45° azimuth loudspeaker at 65 dB SPL at a distance of 2 m. Two meters represented the placement of the student in relation to the teacher in the test classroom and would be consistent with preferential seating. Pearsons, Bennett, and Fidell's (1977) data from public school classrooms indicated that the teacher's voice was approximately 64 dB SPL in the front row (2 m). The hearing aid was placed on KEMAR (Knowles Electronic Manikin for Auditory Research) at this distance (2 m) and the output of the hearing aid (on microphone-only setting) was measured using a probe microphone connected to the Virtual Model 340 Hearing Aid Test System.

Next, the FM microphone and transmitter were placed 6 in. (15.5 cm) from the loudspeaker. The same signal level that produced 65 dB SPL previously was used for the FM system evaluation. This signal produced an intensity level of 84 dB SPL at the location of the FM system microphone. The receiver and neckloop were placed appropriately on KEMAR and the hearing aid was set to telecoil response. The FM receiver volume control was manipulated until the output at 1000 Hz matched the 1000 Hz output for the hearing aid alone set to microphone (as measured by the probe microphone system). In this manner, the FM system coupled to the hearing aid via the telecoil and the microphone response of the hearing aid in the same listening condition were producing the same output to the listener although not necessarily the same gain (Byrne & Christen, 1981; Hawkins, 1984). The FM receiver volume control (volume control = 4) was fixed in this position for the rest of the experiment.

Real ear responses for the M, T, and M/T settings at distances used in the word recognition task. Real ear probe microphone responses were obtained from each ear of the subject with the laboratory hearing aids set to microphone, through the hearing aid microphone response with the hearing aids set to M/T, and through the telecoil response with the hearing aids set to M/T. The volume control of the hearing aid was set to use gain (volume control = 3) for all probe microphone testing. Figure 2 illustrates the measurement technique for the real ear response of the microphone setting. After leveling the equipment with the reference micro-

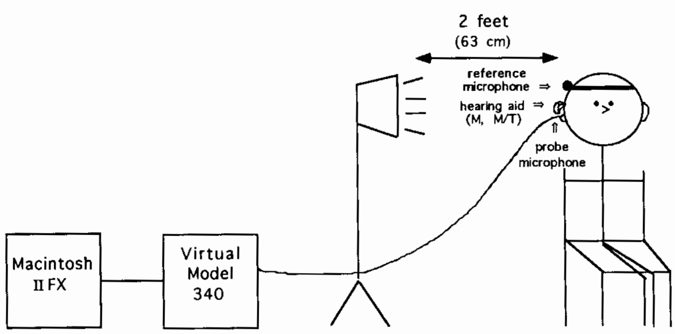

Figure 2. Measurement technique for the real ear response of the hearing aid microphone setting.

phone placed above the hearing aid microphone and the probe microphone placed in the open ear canal, testing began. A 70 dB SPL speech-weighted composite signal was delivered from a speaker placed 2 ft (63 cm) away from the subject. The level, signal type, and placement were chosen to mimic the level and position of a fellow student talking nearby. Figure 3 is a display of the real ear aided response (curve M-only).

The same technique was used to measure the response of the microphone when employing the M/T setting. The only difference was that the neckloop and receiver (in the on position) were placed around the subject's neck and the FM transmitter was turned on outside the test booth (no input signal was provided to the FM transmitter). This condition mimicked the response that would be expected from the hearing aid when the child was using the hearing aid setting (M/T) to listen to both the instructor and fellow students. For this condition, the teacher has stopped talking (no direct input to the FM transmitter) and a fellow student has started talking (63 cm away). Three measurements were conducted in this condition, allowing for manipulation of the relative M/T gain. A potentiometer included with the hearing aid allowed for a *0* setting, a *-10* setting, and a *-20* setting. Each response curve is displayed in Figure 3 and labeled accordingly.

Finally, the telecoil response with the hearing aid set to M/T was evaluated using the test set-up illustrated in Figure 4. The subject remained seated in the test booth with the FM receiver and neckloop. The probe microphone and BTE hearing aid had not been moved from their original position in the subject's ear. The hearing aid was set to M/T with the M/T potentiometer set to 0. The probe microphone speaker was set up outside of the soundbooth with the reference microphone in the position that the FM microphone would normally hold (6 in. or

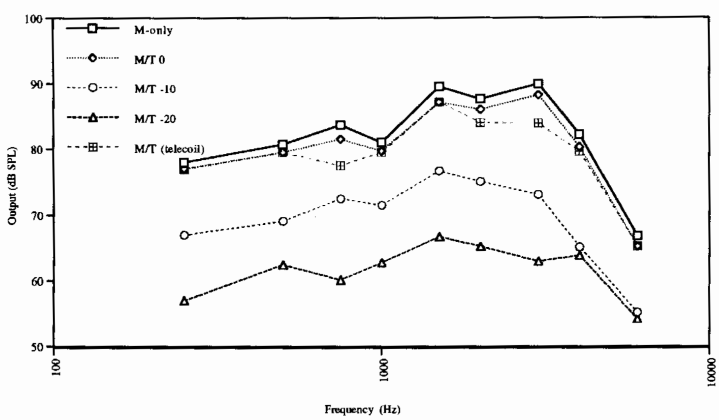

Figure 3. Real ear aided response for five listening conditions.

15.5 cm from the speaker). The system was leveled with this arrangement and then the reference microphone was disabled and taken away (Lewis, 1994). The FM microphone replaced the reference microphone and an 84 dB SPL speech-weighted composite signal was presented through the loudspeaker (level used in the speech recognition task). The response through the hearing aid was measured by the probe microphone and recorded (see Figure 3, M/T telecoil). This procedure was repeated with the M/T potentiometer set at -10 and -20, with the hearing aid set to T-only (no microphone input), and with the subject's head in three other positions (looking over right shoulder, looking over left shoulder, and looking down). Measurements were taken with a variety of head positions to ensure that changes in position during speech recognition testing would not produce different gain/frequency response characteristics of the system (Hawkins & Van Tasell, 1982). The resulting response curves were identical to the response curve for the 0 setting so they have not been included in Figure 3.

The entire procedure described in this section was repeated for the left hearing aid. The electroacoustic results were virtually identical and therefore are not displayed separately.

Room Set-Up

Speech recognition testing took place in a 24 sq ft classroom at the University of Pittsburgh. The subject was seated at a table toward the front of the room. He was 2 m from the teacher location which would represent preferential seating in most classrooms. Speakers were set up on either side of the room directly in line with the sides of the subject's head. A cassette player and amplifier produced a multispeaker babble output to each of these speakers. A Radio Shack sound level meter was used to set the multispeaker babble signal from each speaker to 50 dB

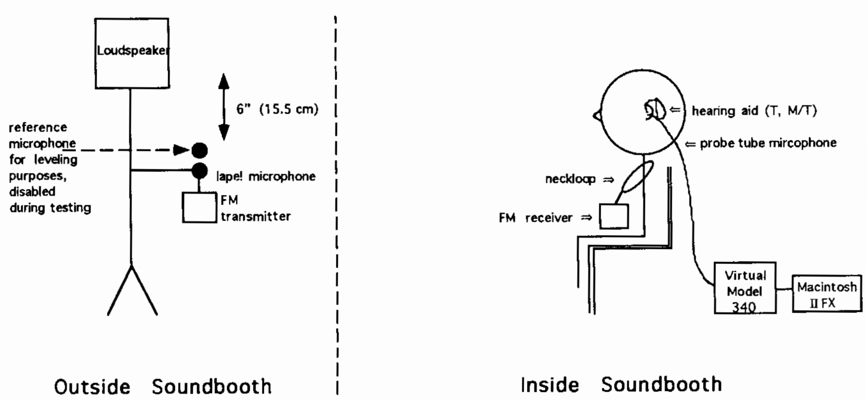

Figure 4. Measurement technique for the real ear response of the M/T and T hearing aid settings.

(A) as measured at the subject's ears in order to mimic average noise levels found in classrooms (Bess et al., 1984; Crandell, 1991). A 50 cm Quasar television with VCR was used to present a videotaped version (female talker) of the revised test of Speech Perception in Noise (SPIN) (Nuetzel, Bilger, & Rzeczkowski, 1980). The TV and VCR were placed on a cart (1.5 m in height) for testing in Location 1 in order to locate the videotaped talker at the height of an average adult standing in front of the room. The structure of the cart also allowed the microphone to be securely attached 15 cm below the TV loudspeaker. For testing in Locations 2 and 3, the TV and VCR were placed on top of student desks in order to mimic the height of a seated student. For these testing conditions (Locations 2 and 3), the FM microphone and transmitter were left in their position on the cart in front of the room. The signal from the television speaker (speech-weighted calibration noise) was set at 84 dB SPL at the FM microphone 15 cm from the TV speaker (Hawkins, 1984, 1987). See Figure 5 for a complete description of testing set-up.

Test Material

The SPIN test consists of a series of high and low predictability sentences. The subject must write down the last word of each sentence. An overall score and high and low predictability scores can be calculated. An example of a high predictability sentence would be "The car drove off the steep cliff." "They had a problem with the cliff" is an example of a low predictability sentence. Twelve

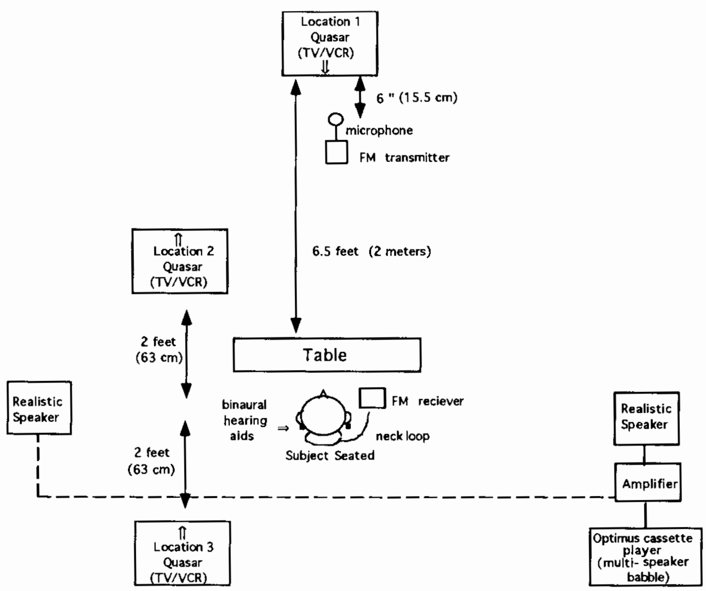

Figure 5. Room set-up and test conditions for the speech recognition task.

different test forms (25 sentences each) were provided for the subject with low and high predictability items combined. Therefore, one test list was used for each listening condition.

Depending on the SNR used and the context evaluated, one does not expect an 11-year-old child to perform similarly to an adult on the SPIN (Elliott, 1979). Based on Elliott's (1979) data, the SPIN can be used with children as young as 11 years old if the child has age-appropriate speech/language development and verbal or writing skills in order to respond. In this evaluation, the SPIN was used as a within-subject measure to compare treatments/listening conditions for one child as opposed to comparing children.

Assistive Device Placement

The William Sound Personal FM system transmitter microphone was placed 15 cm below the speaker of the TV to mimic lapel microphone placement (see Figure 5). The volume control on the FM transmitter was set at 4 for all testing as determined previously. The FM microphone and transmitter were not moved from their placement on the cart at the front of the room for the duration of the evaluation. The subject was seated toward the front of the room and wore the FM receiver, neckloop, binaural laboratory hearing aids (volume control at use setting determined previously), and individual earmolds.

By placing the microphone within 15 cm of the sound source, the signal is transmitted from the near field (as opposed to the far field). There is a chance for much more frequency-specific variability in the signal with changes in microphone and/or speaker placement in the near field. This variability is not seen in the far field (Colloms, 1980). The microphone would have to be placed approximately 1 m away from the television speaker in this test set-up in order to be in the far field for the frequency range of interest (500-8000 Hz). This set-up was not acceptable due to the intensity level that would have been required for the signal to be 84 dB SPL at the FM microphone. To obtain this sound pressure level at a 1 m distance as opposed to 15 cm, a teacher would be shouting. This higher intensity level could easily impact the conditions where the microphone was engaged. The compromise was to create the set-up to mimic a teacher using an FM system as closely as possible (microphone location and sound pressure level) while securing the FM microphone in place via velcro straps. The microphone was not moved during the entire test procedure in order to maintain the frequency content of the signal. It should be noted that this same problem of a variable signal in the near field exists when the signal is coming from the actual teacher to the closely placed microphone.

Procedures

Before testing began, the subject was seated in a chair at the table in the test room. At this time, it was explained to the child and his mother that the child would be presented with a series of sentences and that he would have to write down the last word of each sentence on the spaces provided on each of the 12 SPIN test forms. He was instructed to guess whenever necessary because many of the items would be difficult. Four practice sentences were read in quiet (two high predictability and two low predictability) and the subject wrote down the correct last word for each presentation.

The testing procedure consisted of 12 conditions. The 12 conditions included three different locations for the talker (i.e., the TV and VCR). See Figure 5 for the three locations. Location 1 consisted of the TV and VCR in front and facing the subject to allow for auditory and visual input (simulating a teacher speaking to a class). Location 2 consisted of the TV and VCR in front and to the left of the subject, facing away from the subject (simulating another student sitting in front of the subject). Location 3 consisted of the TV and VCR in back and to the left of the subject, facing forward (simulating another student sitting in back of the subject). In each location, 25 sentences (constituting half-lists) from the SPIN tape were presented for each of four different hearing aid settings (T, M/T with relative gain set at 0, M/T with relative gain set at -10, and M/T with relative gain set at -20). The total test time was approximately 1 hr and 30 min, with one 15-min break at the half-way point.

Scoring

Each of the 12 SPIN test forms was scored for percentage of correct final words identified. An item was scored as correct if the word was correct and if it had all of the sounds of that word (including final /s/ when appropriate). Spelling was taken into account because of the age of the subject. If an item was questionable because of the spelling, three examiners voted as to whether the word written down was phonetically correct. An example of this occurrence was *flod* for *flood*. This item was scored as correct. Scoring revealed that only one item was considered a spelling error (the example provided above) and no incorrect items were incorrect because of a missing plural. Incorrect items were clearly wrong or omitted completely.

RESULTS/DISCUSSION

Table 2 contains the percentage of items correct for each of the 12 conditions that were evaluated. A 10% difference between scores is considered significant for the SPIN when using half-lists (Bilger, Nuetzel, Rabinowitz, & Rzeczkowski, 1984). For teacher listening (Location 1), the T-only, M/T with -10 reduced microphone gain, and M/T with -20 reduced microphone gain produced identical scores (84%). A significant reduction in score (64%) is seen in the M/T 0 setting where the gain of the telecoil and microphone are very similar (slightly more gain for the microphone input). This would suggest a need to eliminate the M/T 0 setting because a compromise in understanding the teacher is not acceptable. It is evident from results for Locations 2 and 3 (student talking in the classroom) that the T-only setting is inadequate for meaningful hearing of other students (4 and 12% correct at these locations). Recall that T-only means that the input was coming from the FM microphone located at the position of the teacher in the front of the room even though that is not where the signal of interest was located. Although the M/T -10 and M/T -20 hearing aid settings provide adequate hearing of the teacher (84%), they do not provide any improvement over the T-only setting for classroom listening (Location 2 = 4%; Location 3 = 12% speech recognition). The M/T 0 setting is the only condition that provides any improvement in classroom listening (24% at Location 2 and 60% at Location 3), but, as mentioned previously, teacher speech recognition is greatly reduced.

Table 2

Percentage Correct on the SPIN Test as a Function of Talker Location and Hearing Aid Setting (Case Study)

	Speaker location		
Hearing aid setting	**Teacher Location 1**	**Front student Location 2**	**Back student Location 3**
T-only	84	4	12
M/T 0	64	24	60
M/T -10	84	12	4
M/T -20	84	8	12

Note. T-only = Hearing aid set to telecoil response. M/T 0 = Hearing aid set to combination microphone and telecoil response with a 0 relationship. M/T -10 = Hearing aid set to combination microphone and telecoil response with a -10 relationship. M/T -20 = Hearing aid set to combination microphone and telecoil response with a -20 relationship.

The original electroacoustic results (see Figure 3) could have predicted the order of these findings. The hearing aid set to M/T 0 provides approximately the recommended amount of gain by frequency for this student (i.e., M-only), thereby providing at least some audibility for signals several feet away (other students). Because of this amount of gain, the noise in the classroom (50 dB in this experiment) is received and amplified through the microphone in competition with the telecoil response which is actually providing slightly less gain than the microphone in this particular condition. Thus we find poorer speech recognition and the best understanding of other classroom signals. In the M/T -10 and -20 condition, the teacher is once again perceived well because the microphone gain has been reduced and the classroom noise should not be in direct competition (in terms of overall level). These two settings, however, produce less gain for classroom signals (e.g., other students asking questions), potentially making these signals less audible than in the M/T 0 setting.

The results from the M/T 0 condition suggest that a student seated behind the student wearing hearing aids will be easier to perceive than a student seated in front. Intuitively, this makes sense. The signal from the rear-seated student would be coming toward the listener, whereas the front-placed student's speech signal would be heading away. In addition, the student wearing hearing aids could make use of visual cues by turning to face the student behind him/her. This would not be possible with the student seated in front of him. During the testing procedures, the subject never turned to face Location 3. A student might need to be encouraged to do this and the teacher might have to point out who is talking so the student could quickly turn to the source. These results should be interpreted with caution, however, because the TV monitor does not completely mimic the baffle effects produced by a real head.

The functional measurement has three notable limitations. The test material (unrelated sentences) is not completely representative of communication in a classroom. One would expect the teacher to be talking about a specific topic and students to be asking questions or offering information regarding that topic. On the other hand, the classroom is a learning environment so material is often new and without much context because of the student's lack of experience. Students also raise their hands and ask unrelated questions and make unrelated statements ("Can I go to the bathroom?" "Jimmy took my pen."). The second limitation involves the continuous multispeaker babble used in each listening condition. Although the signal type is most likely representative of much of the noise in a classroom, it is unlikely that a constant intensity is produced all of the time. Third, in order to create a controlled, replicable test environment a real person could not deliver the signal (SPIN sentences). The use of a videotaped talker projected from a TV screen allowed us to control the presentation but it only roughly mimics a real talker. As mentioned previously, this is most notable in the student location in front of the listener. The baffle effects produced by the television case do not simulate a real head. In light of these limitations, these test conditions should probably be viewed as difficult but probably not the best or worse case in a real classroom situation.

EVALUATION OF TWO VOICE-ACTIVATED FM SYSTEMS

There are two voice-activated FM systems available: Mikroport by Sennheiser and Smart-Mic by Comtek. Each system consists of a voice-activated teacher's microphone connected to an FM transmitter and receiver. The receiver includes an environmental microphone and jacks for coupling to the ear via direct audio input, neckloop (to telecoil), and/or earphone. Each system provides slightly different features. The Mikroport provides a variety of transmitting/receiving channels in order to avoid interference, separate on/off switches on the transmitter and

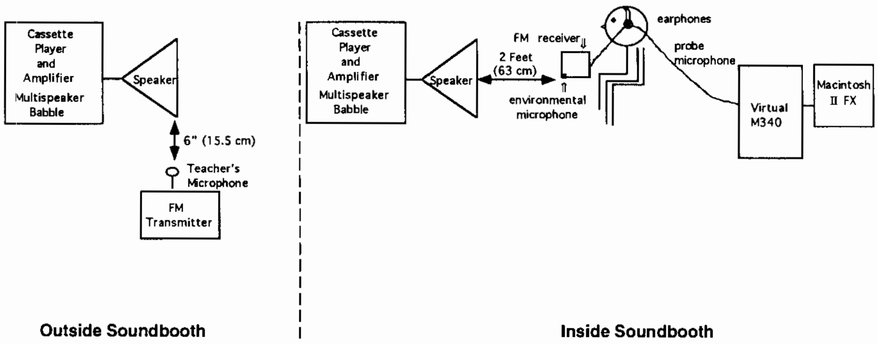

Figure 6. Equipment set-up and measurement technique used for determining the time required for the environmental microphone to provide full output.

microphone, and an indicator light on the receiver when the environmental microphone is in use. The Smart-Mic includes a separate volume control on the receiver, sensitivity control that impacts voice activation, and an automatic *on* function when the coupling device plugs into the receiver.

Equipment Set-Up

The FM transmitter was located outside of the soundbooth. The microphone of the transmitter was located 15 cm away from a loudspeaker in order to mimic a lapel microphone. A multispeaker (12-speaker) babble tape was played from a cassette player and amplifier to the loudspeaker. See Figure 6 for a diagram of the equipment set-up.

The FM receiver was located inside the soundbooth positioned appropriately on KEMAR. The receiver was clipped to KEMAR's belt and earphones were plugged into the receiver and placed on KEMAR's ears. Prior to placing the earphones, a probe microphone was placed in KEMAR's external ear canal and the system was leveled with the reference microphone in the position of the FM receiver's environmental microphone. After leveling, the reference microphone was turned off for testing purposes. The probe microphone was connected to a computer-driven Virtual Model 340 Hearing Aid Test System and the final RMS values for each test condition were read from the screen of a Macintosh computer.

A cassette player and amplifier were routed to a loudspeaker positioned 63 cm (2 ft) from KEMAR. The 63 cm distance was used to mimic the location of a fellow student who might talk within a classroom. A multispeaker babble tape was controlled via the cassette player's pause button.

Calibration of the Test Signals

A sound level meter was used to set the level of the multispeaker babble at 80 dB and 90 dB (RMS) at the location of the transmitter microphone (volume control was marked for each level). These levels were used to portray the range of intensity a teacher might cover. The multispeaker babble used to mimic a fellow student (inside the soundbooth, 63 cm away from the environmental microphone) was set at 70 and 80 dB (RMS) as measured at the location of the environmental microphone. Again, the two levels were chosen to represent a range of possible student voice intensity levels.

Target RMS Values

Because the objective of this investigation was to measure any delay that might exist between the end of the signal from the teacher's microphone to full amplification from the environmental microphone (classroom input), the output from the earphones with both a 70 and 80 dB SPL multispeaker input were documented. These levels (in RMS) then became the target levels for the experimental conditions. Timing ended as soon as the level corresponding to the particular condition (either 70 or 80 dB SPL input) was obtained.

Conditions

The conditions varied by teacher intensity (80 or 90 dB RMS), student intensity (70 or 80 dB RMS), and delay between the end of the teacher's message and the start of the student's question/comment (multispeaker babble). The first delay (from quiet) represented the condition where the teacher had not been talking and a student started to talk. The second delay (30 s) represented the condition where the teacher had stopped talking for 30 s before a student started to talk. The third delay (none) represented the condition where the student started talking as the teacher stopped talking. By combining each of these parameters, 12 conditions were created. The voice-activated systems (Mikroport and Smart-Mic) were evaluated under each condition and the Smart-Mic was evaluated a second time with a different environmental microphone volume control setting selected. So the 12 conditions were repeated three times, producing 36 experimental trials. Table 3 lists each condition by teacher level, student level, and delay.

In order to create the conditions, the investigator operated the pause button on the multispeaker babble tape near the transmitter microphone and monitored the stopwatch, and one assistant operated the multispeaker babble tape near the receiver microphone and monitored the probe microphone measurement of RMS of the environmental signal. The investigator with the stopwatch controlled each condition by indicating to the assistant when to turn on the multispeaker babble (representing the student) by a motion of her hand (this could be seen through the soundbooth window and done instantaneously via the pause button on the cassette recorder). All 36 trials were repeated with the two measurement responsibilities switched. The investigator and the assistant recorded the time that elapsed before the RMS value from the probe microphone in KEMAR's ear recorded the target RMS value that had been obtained previously. The first time taker did not disclose her record sheet until the second time taker had made measurements for the same 36 trials. At that time, the record sheets were compared. The results were identical, so the conditions were not presented a third time. If variable reaction time in starting the multispeaker babble tape or in starting and stopping the stopwatch were a factor, one would not expect such consistent results between two data collectors across 36 trials. Based on this excellent agreement, these delay values can be considered an accurate estimate of true performance.

RESULTS/DISCUSSION

As can be seen in Table 3, depending on which voice-activated system is used, there is a delay of approximately 1.4 to 1.8 s between when the environmental microphone is activated and when the output from that microphone reaches its full level regardless of teacher microphone input level, environmental microphone input level, environmental microphone volume control setting, and delay between deactivation of the teacher microphone and subsequent activation of the environmental microphone.

With the delay between environmental microphone activation and full output (assumed to be the required response for the individual) quantified, several questions need to be addressed to establish the use of this technology in the classroom environment. Nitchie (1930) reported that ordinary speech (in adults) averages

Table 3

Time for the Environmental Microphone to Provide Full Output as a Function of Teacher and Student Intensity Level and Speaking Interval

Condition			Lag time (seconds)		
Teacher level	Student level	Delay	Mikroport	Smart-mic vc (a)	Smart-mic vc (b)
80	70	from quiet	1.4	1.8	1.8
90	70	from quiet	1.4	1.8	1.8
80	80	from quiet	1.4	1.8	1.8
90	80	from quiet	1.4	1.8	1.8
80	70	30 s	1.4	1.8	1.8
90	70	30 s	1.4	1.8	1.8
80	80	30 s	1.4	1.8	1.8
90	80	30 s	1.4	1.8	1.8
80	70	none	1.4	1.8	1.8
90	70	none	1.4	1.8	1.8
80	80	none	1.4	1.8	1.8
90	80	none	1.4	1.8	1.8

Note. vc = volume control setting.

approximately 13 speech sounds per second with some consonants requiring $\frac{1}{16}$ of a second and some vowels lasting $\frac{3}{16}$ of a second. If the rate of speech for children is similar, approximately 18.2 to 23.4 speech sounds may not be adequately amplified by the environmental microphone circuitry in voice-activated FM systems. The author was unable to locate existing data that would determine the impact of this delay on the pediatric listener's ability to follow what has been said by a fellow student. Factors such as the child's ability to use context, the amount of context actually available, the talker's rate of speech, and the talker's use of nonessential prefacing comments to introduce questions or statements (e.g., "I wonder if," "I need to," etc.) might impact the effect of missing the first 1.4-1.8 s of a spoken message.

The classroom communication environment also will impact the successful use of this type of assistive device. The system is based on turn taking. If fellow students speak while the teacher is speaking, the student using the device will not hear their comments (similar to any of the other solutions provided thus far). If the student starts to speak just as the teacher is ending, the student using the device will miss that portion of the statement as well as the 1.4-1.8 s required for the environmental microphone to come on. Considering the physical characteristics of the voice-activated system, it might be most successful in a structured classroom. For instance, if the children are required to raise their hands before any question or comment is made and the teacher points to them as well as calls on them, the student using the device would have time to turn to face the student about to make a comment (visual cues will be available). The students might be required to use a prefacing statement before any real exchange of information in order to allow the environmental microphone to come up to full level. This could be as simple as addressing the teacher by name. One can imagine that this would sound unnatural and create a rather formal environment but it may be a reasonable alternative to one student in the classroom missing out on the exchange of information. The practicality of this suggestion must be evaluated in real classroom environments. Classroom structure generally changes a great deal from kindergarten to high school. This type of device may be more useful during certain periods of the student's academic life.

SUMMARY

The use of FM-only technology (no environmental input) may impede the individual from receiving important auditory information from peers and interactions in the surrounding environment (Maxon, Brackett, & van den Berg, 1991). Although the use of an FM system provides necessary information from the teacher, interactions with peers and those within the classroom also may contribute greatly to an individual's academic success and socialization. Thus, manufacturers and educational audiologists have attempted to produce and use technology that theoretically should provide two audible signals (one from the teacher and one from the surrounding classroom).

The most recent attempts at this have been hearing aids equipped with M/T settings that allow the audiologist to manipulate the output of the microphone as related to the output produced by the telecoil circuitry. The case study examined the use of the variable M/T settings in a variety of listening conditions. When the microphone and telecoil frequency/gain characteristics are set for maximum audibility, the original SNR enhancement provided by the T-only setting may be functionally eliminated.

This problem motivated the introduction of voice-activated technology for use in the classroom. The results of the evaluation reported in this paper illustrate that voice-activated technology depends on linear listening (first one signal, then the next) and creates a slight delay in amplification of the environmental signal. Currently, it is not clear what impact this delay has on student perception or what it might dictate in terms of classroom management.

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