Speech Perception Benefits of FM and Infrared Devices to Children With Hearing Aids in a Typical Classroom

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Children learn in classroom environments that typically have background noise and excessive room reverberation (e.g., American National Standards Institute [ANSI], 2002; Bradley, 1986a, 1986b; Sanders, 1965). The 2002 ANSI standard on acoustical performance for schools has resulted in a heightened awareness of the effects of background noise and reverberation on student speech perception and learning and has established criteria for defining appropriate classroom acoustics. Considerable research has established that degradation to speech perception occurs in a predictable manner as background noise and reflected sound (measured as reverberation time, RT) increase under adverse listening conditions. Children with hearing loss, as well as normally hearing peers, experience these problems (e.g., Bradley, 1986b; Downs & Crum, 1978; Finitzo-Hieber & Tillman, 1978; Irwin & McAuley, 1987; Neuman & Hochberg, 1983). Flexer (1995) speculated that the presence of poor listening conditions also increases the effort of learning and reduces the energy available for performing other cognitive functions.

Children with hearing loss perceive speech in a fragmented manner as a result of the acoustic filter effect that occurs when their hearing aids do not amplify the complete speech signal into their comfortable listening range (Flexer, 1999; Gordon-Salant, 1985). The benefits of personal hearing aids to children in classroom listening environments are also limited by the fact that the hearing aids amplify both background noise and teachers' voices (e.g., Nabelek, Donahue, & Letowski, 1986). The presence of background noise further impairs the ability of these students to perceive and comprehend speech in a classroom setting by

ABSTRACT: Children typically learn in classroom environments that have background noise and reverberation that interfere with accurate speech perception. Amplification technology can enhance the speech perception of students who are hard of hearing.
Purpose: This study used a single-subject alternating treatments design to compare the speech recognition abilities of children who are hard of hearing when they were using hearing aids with each of three frequency modulated (FM) or infrared devices.
Method: Eight 9–12-year-olds with mild to severe hearing loss repeated Hearing in Noise Test (HINT) sentence lists under controlled conditions in a typical kindergarten classroom with a background noise level of +10 dB signal-to-noise (S/N) ratio and 1.1 s reverberation time. Participants listened to HINT lists using hearing aids alone and hearing aids in combination with three types of S/N-enhancing devices that are currently used in mainstream classrooms: (a) FM systems linked to personal hearing aids, (b) infrared sound field systems with speakers placed throughout the classroom, and (c) desktop personal sound field FM systems.
Results: The infrared ceiling sound field system did not provide benefit beyond that provided by hearing aids alone. Desktop and personal FM systems in combination with personal hearing aids provided substantial improvements in speech recognition.
Clinical Implications: This information can assist in making S/N-enhancing device decisions for students using hearing aids. In a reverberant and noisy classroom setting, classroom sound field devices are not beneficial to speech perception for students with hearing aids, whereas either personal FM or desktop sound field systems provide listening benefits.

KEY WORDS: hearing impairment, speech perception, educational technology, amplification, classroom acoustics, HINT

masking lower intensity portions of the speech signal (e.g., Gengel, 1971; Hawkins & Yacullo, 1984; Humes, 1991; Irwin & McAuley, 1987; Nabelek & Pickett, 1974a). In addition, reverberation has been described as having the effect of smearing or distorting the speech signal (Bolt & MacDonald, 1949; Gelfand & Silman, 1979). Finally, there is a synergistic effect of background noise and reverberation that increases the degradation of speech perception more than if a simple additive effect were present (e.g., Bradley, 1986a, 1986b; Finitzo-Hieber & Tillman, 1978; Irwin & McAuley, 1987; Lochner & Burger, 1961; Nabelek & Pickett, 1974a, 1974b; Yacullo & Hawkins, 1987). In addition to adverse acoustic conditions, distance from the speaker also degrades the speech signal and can significantly affect speech perception (Crandell & Smaldino, 1994; Leavitt & Flexer, 1991). Hearing aids have limited ability to improve speech perception as the signal degrades across listening distance.

The long-standing recognition of the degradation of the speech signal within classrooms has resulted in the widespread use of educational amplification technology in school by children who are hard of hearing (Berg, 1976). For example, frequency modulated (FM) or infrared listening devices are used to improve the signal-to-noise (S/N) ratio at the listener's ear level by placing on the teacher a microphone transmitter that delivers an amplified signal over FM radio waves or infrared light waves to a receiver device. The receiver delivers the amplified signal to the child's hearing aids via a personal FM system or through the sound field to one or more speakers in the classroom. This manner of amplification of the teacher's voice provides a consistent signal regardless of how far the student is from the teacher within the classroom setting. Developments in educational amplification technology have made a variety of FM or infrared devices available to improve listening in classrooms for students with and without hearing losses. Numerous studies have compared the benefit of using different adaptations of personal FM systems or sound field FM systems under varying classroom acoustic conditions (e.g., Blair, Myrup, & Viehweg, 1989; Crandell, Charlton, Kinder, & Kreisman, 2001; Crandell, Holmes, Flexer, & Payne, 1998; Flexer, Richards, Buie, & Brandy, 1994; Sarff, Ray, & Bagwell, 1981).

Investigators have explored the benefits of personal FM and sound field FM devices to speech perception. For example, under classroom acoustic conditions that meet the current ANSI standards, the use of an ear-level FM system can result in an improvement in word discrimination up to 20% (Picard & Lefrancois, 1986) as long as the individual with hearing loss has a word discrimination ability in quiet of at least 40% to 60% (Boothroyd & Iglehart, 1998). An improvement in word discrimination of up to 25% can occur under ideal reverberation conditions (i.e., 0.3 RT; Boothroyd & Iglehart, 1998). Even in a low reverberation environment, performance is better with devices presenting the improved signal within the critical listening distance than with presentation of the signal by sound field FM or infrared devices presenting the teacher's voice throughout the classroom (Nabelek & Donahue, 1986; Nabelek et al., 1986; Noe, Davidson, & Mishler, 1997). For full access to verbal instruction, a child with hearing loss needs the primary signal to be presented within the critical listening distance (American Speech-Language-Hearing Association [ASHA], 2002; Crandell et al., 1998; Picard & Lefrancois, 1986) or in an environment that has an RT of less than 0.4 s (Blair et al., 1989; Noe et al., 1997).

Although researchers have compared S/N-enhancing devices, there has been no controlled study comparing the benefits of personal FM systems with desktop or classroom sound field FM or infrared systems for individuals with hearing loss listening in a classroom environment with typical levels of noise and reverberation (ASHA, 1995). Currently, school teams make purchasing decisions about educational amplification technology without the benefit of empirical research results indicating the level of improvement in speech perception that can be anticipated with the use of one type of equipment over another under typical classroom listening conditions (Maxon, Brackett, & Van Den Berg, 1991). Speech perception, or how well words or sentences can be understood under controlled conditions, can be measured as children use different types of S/N-enhancing devices. This study investigated the relative benefits of classroom amplification technologies (personal FM, infrared sound field from classroom speakers adjacent to the ceiling, and desktop sound field FM) that are now commonly used with children who are hard of hearing in typical classrooms.

It was hypothesized that children using hearing aids would perform differently when using different educational amplification technology and that they may prefer using some types of educational amplification technology over others, especially if social factors, as well as their speech perception performance, influence their choices. This investigation set up a controlled listening task that was meant to reflect how young listeners who are hard of hearing might perform in typical noisy classroom listening environments when a teacher positioned in front of them presents speech with some predictability. The three primary purposes of this study were to investigate:

- the speech recognition abilities of children using hearing aids who are hard of hearing when they listen under typical classroom noise and reverberation conditions;
- the effects of three types of educational amplification technology on the speech recognition abilities of these same children (sound field infrared amplification system in the ceiling, sound field speaker placed on the student's desk, and personal FM system with direct audio input into each child's hearing aid); and
- participant and parent opinions on which educational amplification system was preferred under these controlled, comparative conditions.

METHOD

Participants

Eight children between the ages of 9 and 12 who had hearing impairments and who were primarily auditory communicators and learners were recruited from a large school district to participate. The participants were educated in inclusive general education classrooms without manual communication support (i.e., sign language) or the need for academic special education support services. School records documented that all participants had normal intelligence, language abilities within 1 year of their age peers, and no identified disabilities other than hearing impairment. All participants had speech intelligibility sufficient to allow conversational speech to be understood by adult listeners experienced with the typical articulation patterns of children who are hard of hearing.

Participants included 4 boys (1 Asian, 1 African American, and 2 Caucasian) and 4 girls (1 Hispanic and 3 Caucasian). All participants were proficient English speakers and were placed in regular classrooms where the instruction was in English.

Participant ages and hearing loss data are shown in Table 1. Participants met the following two criteria: (a) a congenital hearing loss of mild to severe degree or hearing ability that was normal in the low frequencies but of at least mild to severe degree above 1000 Hz, as evidenced by an audiogram obtained within 1 year of the date of investigation; and (b) aided speech recognition thresholds under sound field conditions that were within the normal hearing to mild hearing loss range.

Setting

Listening environment. This investigation was performed in a kindergarten classroom, representative of a typical classroom listening environment. The dimensions of the teaching area in this room were 11.9 × 7.6 × 2.7 m, with an additional 2.4 × 5.2 m of open shelves and coat cubby area. This large kindergarten room had a volume of 244.2 m^3. There were 90.4 m^2 of carpeted area and 140.2 m^2 of linoleum floor covering. The participant seating position was on the linoleum, where student tables were typically placed.

The distance of a student from the teacher influences speech recognition. The critical distance refers to that point in a room at which the intensity of the direct sound is equal to the intensity of the reverberant sound. In an average sized classroom (150 m^3), the critical distance would be slightly greater than 2.7 m from the teacher (Crandell & Smaldino, 1994). Thus, most listeners in classrooms are beyond the critical distance and in the indirect sound field. To achieve an appropriate critical distance, the classroom was set up with a simulated teacher 1.7 m in front of the blackboard and 3.4 m from the wall parallel to the front wall. The simulated teacher consisted of a compact disc player on top of an Audio Enhancement (Bluffdale, UT) Omni Petite sound field speaker located in

Table 1. Age (years;months) and hearing threshold information in dB HL for 8 participants.

Child	*Age*	*Ear*	*250 Hz*	*500 Hz*	*1000 Hz*	*2000 Hz*	*4000 Hz*	*8000 Hz*	*PTA*
1	9;10	Right	50	70	85	80	75	60	78
		Left	50	60	85	80	70	65	75
		Aided	10	15	30	35	20		27
2	10;3	Right	50	50	65	65	65	75	60
		Left	30	40	65	60	65	90	57
		Aided		25	20	30	35		25
3	10;3	Right	5	10	20	70	90	85	33
		Left	5	5	30	65	80	85	33
		Aided		10	10	20	40		13
4	9;2	Right	20	55	70	90	65	105	72
		Left	25	60	70	60	60	80	63
		Aided		25	25	20	20		23
5	11;5	Right	5	35	40	45	45	65	40
		Left	55	50	60	65	65	70	58
		Aided	10	10	15	20	20		15
6	9;7	Right	15	25	40	50	55	70	38
		Left	20	25	45	45	55	70	38
		Aided		5	5	10	15		7
7	10;2	Right	35	30	50	55	60	70	47
		Left	30	30	55	60	65	70	47
		Aided		20	20	25	30		22
8	11;11	Right	60	65	85	75	70	85	75
		Left	55	55	85	70	75	105	70
		Aided		30	25	25	40		27

Note. PTA = pure-tone average.

the front of the classroom. This speaker was selected because of the high fidelity representation of the speech spectrum, as compared to speakers that are designed to deliver music. To simulate a teacher instructing from a standing position in the front of a classroom, the center of the loudspeaker height was 1.4 m from the floor. The volume of the speech stimuli was set so that it averaged 83 dBA at 8.9 cm from the center of the Omni Petite sound field speaker. This 8.9-cm distance was selected to represent the preferred distance for microphones to be worn from a teacher's mouth (Crandell & Smaldino, 1994). The participants were seated 3 m from and directly in front of the Omni Petite sound source. This was beyond the critical listening distance for the classroom. The seat was taped to the floor to maintain constant placement for all participants. At the position of the participant's head, the speech stimulus was measured with a Quest 2700 (Oconomowoc, WI) sound level meter and set to have an intensity of 70 dBA SPL. The distance from the desktop sound field speaker and the head position of the participants was approximately 68.6 cm, with some variation depending on child height.

Background noise. The S/N ratio of a classroom is determined by subtracting the intensity of the primary speech signal from the intensity of the background noise. The range of background noise, defined as any unwanted sound source, typical of classrooms is 53–74 dB SPL, with noise levels in public school classrooms averaging 60 dB SPL (Olsen, 1977). Background noise level measurements were obtained using a Quest 2700 sound level meter positioned at the approximate ear level of the participants before data collection, using the A-scale as well as the octave bands by using a Quest OB-50 octave filter. The classroom ventilation fan was audibly circulating air during all data collection, producing a sound pressure level of 54 dBA at participant ear level. In order to achieve an S/N representative of typical classrooms (Olsen, 1977), hospital cafeteria noise was presented from an audio cassette player at a 45° angle, 3.7 m behind and to the left of the participant listening position. The volume of the tape was a constant 60 dBA noise level at participant ear level (+10 dB S/N). Hospital cafeteria noise was selected for use in this study because it has voice babble and random noise clatter—extraneous sound sources that are commonly present in classrooms. The cafeteria noise was modified using a digital speech processor to clip the intensity peaks so that it had a spectral shape that is similar to multitalker babble, which has been found to have a spectral shape that is similar to the background noises commonly encountered in everyday educational situations (Crandell & Smaldino, 1994). The ventilation noise and the cafeteria noise had the following intensity in SPL at the discrete frequencies as measured by the Quest OB-50 octave filter set: 57 dB SPL at 31 Hz, 57 dB SPL at 63 Hz, 61 dB SPL at 125 Hz, 61 dB SPL at 250 Hz, 63 dB SPL at 500 Hz, 55 dB SPL at 1000 Hz, 50 dB SPL at 2000 Hz, 36 dB SPL at 4000 Hz, and 33 dB SPL at 8000 Hz.

Reverberation. RT is the portion of a second it takes a 60 dB SPL sound to completely diminish in a room space. The longer the RT, the greater the impact on speech perception. Typical RT present in unoccupied classrooms ranges from 0.5 to 1.2 s (Crandell & Smaldino, 1994). Reverberation for this study was determined via measurement using a Goldline GL-60 (West Redding, CT) reverb time meter. A sound source was introduced and reverberation was measured using the –15 dB SPL reference point at 2000 Hz. Stability was achieved at this setting, thus allowing other frequencies to be measured reliably. All measurements were obtained at the participant's seating position. The average of 500, 1000, and 2000 Hz RTs was estimated at 1.1 s. In four other studies, the following reverberation ranges have been identified in typical classroom listening environments: 0.4 to 1.1 s (Kodaras, 1960), 0.6 to 1.0 s (McCroskey & Devens, 1975), 0.5 to 1.0 s (Nabelek & Pickett, 1974a), and 0.4 to 1.2 s (Crandell & Smaldino, 1994). Thus, the kindergarten classroom used for this investigation was at the higher end of the common range of RTs.

Hearing Aids

All participants were longtime binaural hearing aid users. As is indicated in Table 1, hearing aids worn by the participants were adequate for improving aided thresholds to expected levels. Seven of the eight participants wore Novo Forte 3 hearing aids that had been programmed specifically to meet auditory targets of each individual participant. These were the hearing aids that the students wore at school; they allowed relative consistency of amplification for the purposes of this study. The Novo Forte 3 (Phonak, Warrenville, IL) hearing aids link with MicroLink ML7 (Phonak, Warrenville, IL) personal FM receivers via direct audio input and allow students to change frequency modules as they move between different teaching environments. Novo Forte features include a choice of linear and nonlinear signal processing strategies, highly flexible filtering, and many other quality and performance features geared toward optimal fittings for children.

The goal in fitting children with amplification is to make the long-term average speech spectrum available throughout the frequency range so that a child can perceive the speech sounds (Jupiter, 1997). The Novo Forte 3 hearing aids were programmed according to manufacturer's program specifications using a NOAH platform computer program to determine individual targets to match participant's audiometric profiles and to subsequently program the Novo Forte 3 hearing aids to match these targets. A National Acoustics Laboratories (NAL) target was used for all real ear measurements. Participant 4 was an exception in that personal Widex C19 (Lisle, IL) digital hearing aids were used with the MLX FM receivers. The procedures to set these hearing aids to target were determined by Widex. The noise control circuit was not activated on the Widex C19 hearing aids. All hearing aids had been tested electroacoustically using a Fonix 500 (Tigard, OR) electroacoustic analyzer and real ear testing had been performed on all participants using these hearing aids 4–5 days before the data collection date in order to reduce the level of fatigue of participants on the day of data collection.

In summary, 7 of 8 participants wore programmable analog hearing aids and 1 participant wore digital hearing aids, all of which were programmed to match their individual audibility targets. Once set by the educational audiologist, the volume controls on the hearing aids were not adjusted by the participants; however, a subjective loudness measure was used to ensure that no device was providing uncomfortably loud amplification. Hearing aids were worn by participants throughout the investigation, including when responses were obtained using each of the S/N-enhancing devices.

Amplification Systems

The speech signal was delivered by a speaker (representing the teacher) to a microphone transmitter placed 8.9 cm from the speaker. Two different types of FM systems and an infrared classroom sound field system were used to provide an improved S/N ratio within the classroom setting. The amplification equipment selected represented devices that were of recent manufacture and in widespread use in classrooms. This state-of-the-art technology is comparable to other devices on the market that have the same frequency range and similar quality of microphones and other electronic components. Selection was not for the purpose of endorsing certain manufacturers' equipment, as there are multiple manufacturers with devices that fulfill the same function at essentially the same quality as those devices selected.

Before data collection, each participant identified the level of loudness presented by his or her hearing aid and each of the S/N-enhancing devices with the assistance of a pictorial 7-point loudness chart. The chart had line drawings of a child's head arranged vertically on the page and a number and descriptive words next to each head. Each head had a facial expression that corresponded to the descriptive words. The descriptive words in order of loudest, number seven, to quietest, number one, were as follows: hurts, too loud, a little bit loud, just right, a little bit soft, too soft, nothing. Children who are as young as 4 to 7 years have been found to make relatively accurate loudness judgments with similar protocols (Kawell, Kopun, & Stelmachowicz, 1988). The participants listened to practice sentences and were asked to choose the number on the loudness scale that represented their perception of the loudness of each device. The purposes of the loudness assessment were to ensure that the devices were not uncomfortably loud (number 7) for the individuals and to provide a means by which subjective loudness could be used to explain individual differences in performance with the S/N-enhancing devices. The loudness assessment results are included in Table 2.

Classroom infrared sound field system (two speakers adjacent to the ceiling). The classroom sound field system was a TeachLogic IR-2500 (Laguna Hills, CA) sound field amplification receiver and speaker system with a TeachLogic IRB-10 infrared wireless transmitter. It had two speakers mounted at the juncture of the ceiling and wall at approximately 60° and 240° from the position of the participant's seat when facing 0° azimuth to the speaker used to present speech stimuli. The 1.1 s RT present in this classroom proved to be a challenge for setting the loudness of the classroom infrared sound field system within the approximate 10–15 dB amplification of the teacher's voice typical of this technology (Lewis, 1995). When set at +10 dB S/N, the amplification effect was imperceptible as a listening benefit from the participant's seating position. A loudness setting of 11:00 on the volume dial, relative to the top of the front face of the equipment, was selected and was found to deliver a 75 dBA signal, or +15 dB S/N louder than the background noise.

Personal sound field system (desktop). An LES 390 Desktop SoundPak manufactured by LightSpeed Technologies (Tualatin, OR) is a small self-contained unit similar to a standard computer speaker that has sound characteristics that are optimal for high-fidelity replication of speech. The desktop speaker was taped into position at 0° azimuth, 35.6 cm from the table edge closest to the participant. It has a top-mounted volume control that is highly variable; however, the dynamics of a classroom require a volume level that is comfortable for surrounding normal hearing students. Two adult listeners with normal hearing determined an appropriate level to provide comfortable listening over the reverberation and the multitalker background noise, but also a level that would not be likely to interfere

Table 2. Participant ratings during loudness assessments for each listening condition.

Participant	*Hearing aids only*	*Infrared sound field*	*Desktop FM*	*Personal FM*
1	5	4	4–5	5–6
2	3	4	5	4
3	4	5	5	4
4	3	4	4	4
5	4	5	4	4
6	4	5	5–6	4
7	5	5	5	4
8	5	4	5–6	4
Mean	4.1	4.5	4.8	4.2

Note. 1 = nothing, 2 = too soft, 3 = a little bit soft, 4 = just right, 5 = a little bit loud, 6 = too loud, 7 = hurts.

with class dynamics. A Quest 2700 sound level meter was used at the ear level of the participants to determine loudness when the desktop sound field system was set with the control knob indicating a 6:00 setting relative to the front face of the equipment. The resulting intensity was 80 dBA, which was +20 S/N louder than background noise.

Personal FM system (MicroLink). The personal FM system used in this investigation was a Phonak MicroLink ML7 ear-level receiver and an ML4 transmitter. For 7 of the 8 participants, MicroLink ML7 personal FM receivers were linked via direct audio input to Novo Forte 3 hearing aids that had been programmed specifically and verified through real ear measurements to meet auditory targets of each individual participant. Participant 4 was an exception in that Widex programmable hearing aids were used with an MLX FM receiver.

The MicroLink personal FM system has direct input into a participant's hearing instrument and can be set to receive signals from the FM transmitter only or to allow signals from the hearing aid to be received with a preference for the signal from the FM transmitter. The MicroLink ML7 FM receivers were set on the environmental microphone plus FM during data collection, as use of environmental microphones is typically considered to be necessary for child-to-child communication and self-monitoring of voice during FM system use (Ross, 1981).

With an input of 83 dBA at the transmitter microphone and 60 dBA level of background noise received at the ear level of the participants, the S/N of the MicroLink ML7 FM would be logically anticipated to be 23 dB SPL. However, this high S/N cannot be assumed. When an input exceeds 70 dB SPL, the compression threshold of the MicroLink ML4 transmitter is exceeded and the signal is compressed. Because the participants were tested with the environmental microphones, as well as receiving the FM signal, any reduction of gain in the FM signal would attenuate the S/N at the participant's ear (Boothroyd & Iglehart, 1998). Even if the S/N of the MicroLink personal FM and the desktop sound field system were highly similar, the advantage of personal FM would be that it delivers a signal directly to the child's hearing aids, thus preventing degradation of sound from a distance due to reverberation or noise.

Speech Stimuli

Sentences were selected for this investigation to simulate listening to verbal instructions, while controlling for possible gaps in language that often occur in children who have hearing loss. Participants were required to verbally repeat sentences from the Hearing in Noise Test (HINT; House Ear Institute, 1996). The HINT is a version of the Bamford-Kowal-Bench (BKB) Standard Sentence Lists (Bench & Bamford, 1979; Bench, Koval, & Bamford, 1979; Kenworthy, Klee & Tharpe, 1990) that has been modified using vocabulary typical of English speakers in America. HINT sentences have a first-grade reading level and were presumed appropriate for 9- to 12-year-olds who are successfully educated full time in inclusive classroom settings. The HINT consists of 25 syntactically and semantically equivalent sentence lists, each containing 10 sentences. Only 150 sentences containing five words each were recorded for this investigation. Examples of three HINT sentences are *Big dogs can be dangerous, Flowers grow in a garden,* and *They waited for an hour.*

HINT sentences have not been controlled for context predictability and can be considered realistic of classroom listening tasks (Crandell & Bess, 1986). All test sentences were presented only once during data collection. The selected HINT lists were recorded in an anechoic chamber using monitored live voice recording by a female speaking a General American English dialect. There were a total of 50 key words per HINT sentence list. Three sets of HINT lists, or a total of 30 sentences, were presented per listening condition. Fifteen additional HINT sentences were recorded for the purpose of practice before the initiation of testing. Three practice sentences were presented before each of the HINT sentence lists to provide an opportunity for the participants to become familiar with listening to each test condition.

Experimental Design and Conditions

A single-subject experimental design, an alternating treatments design, was used to compare the effects of the three amplification conditions. This experimental design specifies that stimuli are administered in different treatment conditions with the order of the treatments randomized across participants (Barlow & Hayes, 1979; Kazdin, 1982). Repeated exposure to the varying conditions is provided to determine whether there are consistent differences in individual performance. Thus, individual differences over time are readily apparent in the visual inspection of the data and are not masked by group means. In single-subject experiments, visual inspection of graphed data is the primary means by which a decision is made about the extent to which experimental control is demonstrated. The experimental control would be evident if performance in one condition is consistently higher or lower than in other conditions for each individual (Kazdin, 1982). If several individuals demonstrate similar patterns of performance, then one can argue that these experimental effects are reliable. Because insufficient individuals are studied and they are not randomly selected from a large population, claims of generality are restricted to individuals with similar characteristics. However, confidence is enhanced as effects are replicated with more participants.

The participants wore hearing aids during all listening conditions. Following the presentation of 15 practice HINT sentences, three HINT sentence lists of 10 sentences each were presented, with participants using only their hearing aids to establish baseline performance. Then, each participant listened to and repeated three HINT sentence lists per experimental amplification condition. These nine sentence lists were presented in the same order; however, the sequencing of amplification conditions was counterbalanced across the 8 participants.

Three practice sentences were presented when each amplification condition was introduced in order to allow participants to adjust to the level of attention and effort required for listening to each of the amplification devices before the introduction of test sentences. Once testing began, no repetition of any of the 10 test sentences occurred. Brief breaks occurred after every three sentence lists. The alternating treatments design was used to examine whether consistent differences in speech recognition were evident for each participant in the three amplification conditions and whether these conditions were superior to baseline performance.

The listening condition that provided the greatest benefit to each individual was identified and was continued for three final HINT lists to determine whether performance remained stable under a so-called replication condition. The decision of which educational amplification device resulted in superior performance was determined by adding up the three scores for each of the devices, averaging them, and selecting the device with the best performance averaged across the three word lists. Mean accuracy in sentence repetition had to differ by at least one word correct to qualify as a superior performance. One participant did not meet this criterion; therefore, the hearing aid only condition was repeated.

Scoring Participant Responses

Two experienced educational audiologists rated participant responses independently. The listening setting included a constant level of background noise, which made listening to participant responses challenging. Scoring was based on the number of words in each sentence that were repeated correctly. An incorrect response was defined as substituting or omitting a word. Some errors typical of speech patterns associated with hearing loss were not considered inaccurate for the purpose of this study, and the rater response forms listed all acceptable responses. All other differences in articulation production were counted as errors. During the brief breaks provided after every three HINT lists, raters totaled the number of words spoken incorrectly for each list. Interrater response agreement was calculated for 100% of the data and is reported as the percentage of word-by-word agreement for key words in the Results section.

Social Validation

Although it is critical to obtain the recommendations of informed professionals when deciding which style of S/N-enhancing system to purchase, there are factors related to the child's age, personality, self-confidence, and assertiveness that are considered when selecting an S/N-enhancing device (Maxon et al., 1991). It is not uncommon for children to reject educational amplification technology because of cosmetic concerns. In addition, parental opinion about the need for educational amplification technology may influence the child's acceptance (Maxon et al., 1991). Therefore, it is important to factor the opinion of the student into selection of an appropriate device, along with degree and type of hearing loss and other important factors related to the student's ability to function in the classroom.

The primary purpose of measuring social validity was to determine how well the participant's preferences for S/N-enhancing technology agreed with their level of performance with the different devices. Following completion of all the testing trials, participants were asked about their preferences of amplification conditions using the questions in the Appendix. The five questions were written at a Flesch-Kincaid 2.1 grade level, so that the questions were simple for the participants (grades 4–6) to comprehend.

Parents accompanied 7 of the 8 child participants and were requested to complete a social validation survey that was comparable to that completed by the children (see the Appendix). The purpose of the parent questionnaire was to determine if S/N-enhancing technology selection would correspond to the instrument associated with the highest accuracy, based on the children's performance with different devices.

RESULTS

Reliability

Validity of results relies on a high level of reliability in response scoring as per an assessment of interobserver agreement (Kazdin, 1982). There were 15 word lists, each with 50 words, for a possible total correct of 750 words per participant. The number of words that the raters scored the same was divided by the 750 possible words to determine the interobserver agreement percentage for each participant. The overall interobserver agreement between the two scorers was quite high—99.1%.

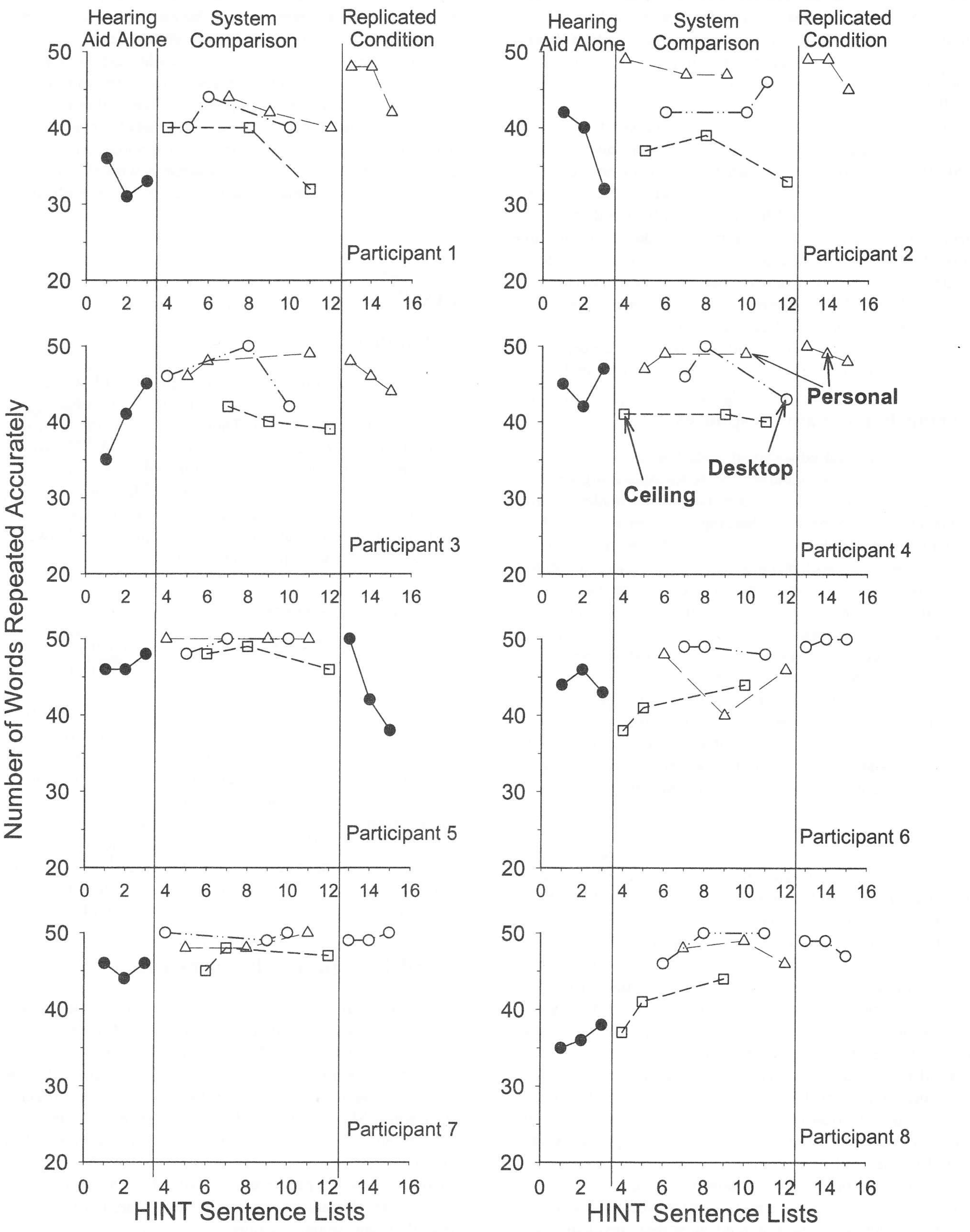
Loudness Assessment

Table 2 provides the participant assessment of the subjective loudness of each educational hearing technology. The results of the subjective loudness assessment revealed that these participants were inconsistent in their report of the loudness of each device. Although it was anticipated that there would be some variability, it was expected that the participants would subjectively judge their hearing aids and the classroom sound field system as being quieter than the desktop or personal FM systems that deliver the amplified sound directly to the ears. The mean subjective loudness assessment results indicated intensity levels from least to greatest as being hearing aids, personal FM, classroom sound field, and desktop sound field.

Word Recognition Performance

Figure 1 displays word recognition results under the various experimental listening conditions for each participant. Participants 4, 5, 6, and 7 had relatively high levels of accuracy while using their hearing aids alone, leaving relatively little room for improvement in speech perception when S/N-enhancing devices were in use. Only Participant 5 responded so close to ceiling that no clearly superior S/N-enhancing device was evident. Visual inspection of the performance data of each participant during the alternating treatment design comparison revealed four main findings.

Figure 1. Speech recognition accuracy scores in an alternating treatments design for 8 participants. Filled circles represent hearing aids alone, open squares represent the addition of the infrared sound field system in the ceiling, open triangles represent the addition of the desktop sound field system, and open circles represent the addition of the personal FM systems.



First, there appears to be no enhancement to performance associated with the use of ceiling sound field amplification over using hearing aids alone. Considerable overlap was apparent in the range of scores for the hearing aid only and the infrared sound field conditions for all 8 participants. Participants 4 and 6 appeared to perform more poorly with classroom sound field systems than with their hearing aids alone.

Second, the data indicated a consistent benefit to using desktop and personal FM systems over the use of hearing aids alone. Six of the participant responses demonstrated a clear separation in their word recognition scores between the hearing aids alone condition and both the desktop and personal FM system conditions. Participant 4 had minimal separation between desktop sound field system and the hearing aid alone, but a consistent benefit was evident for the personal FM system. Participant 6 had one sentence list when personal FM was used that had a score that was substantially lower than the other two personal FM sentence lists. This child spoke English as a second language and four word errors were surmised as being related to syntactic differences between Spanish and English. There was a clearly defined benefit to the use of the desktop sound field system over hearing aids alone for this participant.

A third finding was the lack of a consistent difference between the degree of benefit provided by the desktop sound field system as compared to the personal FM system. Five of the 8 participants evidenced no clear separation to indicate superior benefit between these two devices.

Finally, the 7 participants who had replication trials with S/N-enhancing devices continued to demonstrate performance consistent with the alternating treatment design condition. Only Participant 1 showed further improvement. Participant 5, who had performed consistently above 93% correct in all conditions, actually showed a drop off, lower than the baseline condition, for the final two lists when the hearing aid only condition was reintroduced (as he seemed to fatigue).

Table 3 provides a summary of the mean accuracy of participant responses per condition. Calculated from the three sentence lists per condition per participant, the mean scores were 82.4%, 83.1%, 93.5%, and 94.4% correct for hearing aid, infrared sound field, desktop, and personal FM conditions, respectively. To provide an estimate of the effect sizes, a one-way repeated measures analysis of variance (ANOVA) was conducted, testifying to a highly significant differential effect [$F(3, 21) = 18.1$, $p < .001$, $\eta_p^2 = .72$]. A pairwise multiple comparison procedure (Tukey Test) revealed that the hearing aid and sound field conditions did not differ, nor did desktop FM and personal FM conditions. However, both the hearing aid and the infrared sound field conditions differed significantly from the desktop and personal FM conditions. With a pooled standard deviation of 8.9, these effect sizes were greater than 1 *SD* ($d = 1.2$–1.3).

Social Validation

Responses on the social validation instruments are presented in Table 4. Six out of 8 participants' preferences for a particular educational amplification system agreed with their superior performance with either the desktop or the personal FM systems. Participant 3 chose the classroom infrared sound field system and, when asked, stated that other children in her class and her teacher liked the classroom sound field system. Therefore, it was felt that social approval issues unrelated to personal listening choice overshadowed this participant's choice of educational amplification device. Participant 6 selected the desktop FM as being the system that was easiest for her to listen to; however, she chose the personal FM system as her system of choice for use in the classroom.

The parent of Participant 3 did not observe speech perception testing under the different listening conditions; therefore, no parent responses were obtained for Participant 3. Results of the parent responses to the social validation measure revealed that 6 of the 7 parents who responded were in agreement with their child on which educational amplification device provided the greatest ease in listening. Only 3 parents had responses that agreed with their child's response about which FM device would be preferred by the classroom teacher. Only 1 parent/child dyad agreed on which FM device would be most acceptable to classmates. Five of 6 parents who stated a preference for a specific FM device were in agreement with the judgments of their

Table 3. Mean accuracy of participant responses for each listening condition.

Participant	*Hearing aids only*	*Infrared SF*	*Desktop FM*	*Personal FM*	*Replication*	
1	68.0%	74.6%	84.0%	86.7%	92.0%	P
2	76.0%	71.3%	86.7%	95.3%	95.3%	P
3	80.6%	82.0%	92.0%	95.3%	92.0%	P
4	89.3%	84.0%	92.7%	96.7%	98.0%	P
5	93.3%	95.3%	98.7%	100.0%	88.0%	HA
6	88.7%	82.0%	97.3%	89.3%	99.3%	D
7	90.7%	93.3%	99.3%	97.3%	98.7%	D
8	72.7%	82.0%	97.3%	94.7%	96.7%	D
Mean (SD)	82.4 (9.4)	83.1 (8.2)	93.5 (5.7)	94.4 (4.3)		

Note. P = personal FM, HA = hearing aid alone, D = desktop sound field system.

Table 4. Preferences for amplification technology by participants and parents as compared to the actual listening condition(s) that resulted in superior performance.

		Student ratings					*Parent ratings*				
Participant	*Superior device*	*Easiest listening*	*Perceived teacher preference*	*Classmate acceptance*	*Prefer to use in class*	*Do not want in class*	*Easiest listening*	*Perceived teacher preference*	*Classmate acceptance*	*Prefer to use in class*	*Do not want in class*
1	D + P	D	D	D	D	C	D	P		P	C
2	P	P	D	D	P	C	P	D	P	P	C
3	D + P	C	C	D	C	P					
4	P	P	P	C	P	C	P		P	P	D
5	D + P	P	C	D	P	D	P	P	P	P	D
6	D	D	P	D	P	C	D	D	D		
7	D + P	P	P	P	P	D	D	C	C	C	
8	D + P	P	P	P	P	C	P	P	D	P	C

Note. D = desktop sound field system, C = ceiling sound field system, P = personal FM.

children. Finally, 5 of the 7 parents responding specified which FM device they would not want to be used in their child's classroom. Three parent/child dyads were in agreement that they would not prefer to use the ceiling sound field FM technology. One parent and child were in agreement of their choice of the desktop FM as the least preferred technology; just as they had been in agreement that the personal FM system was the FM device of choice. Participant 2 preferred to use the personal FM system, as did the parent; however, the child chose the ceiling sound field FM and the parent chose the desktop FM device as the least preferred educational amplification technology.

DISCUSSION

Despite state-of-the-art digital or programmable analog hearing aids, participants still demonstrated better speech recognition when using S/N-enhancing devices when listening in this relatively noisy and reverberant classroom listening environment. The speech recognition results of this single-subject experiment support the use of desktop or personal FM systems by children who are hard of hearing. The use of sound field amplification with speakers placed adjacent to the ceiling in a reverberant and noisy classroom did not improve speech perception performance over the use of hearing aids alone.

When the degree of improvement in speech perception is considered, the question of what is a meaningful difference is an important one. Participants 1 and 8 demonstrated the greatest differences, accurately repeating 68% and 73% of the words, respectively, using hearing aids alone, contrasted with 92% and 97% in the final personal FM replication condition. Of the 8 participants, Participants 1 and 8 also had the greatest degree of hearing loss. Conversely, Participant 5, who had amplified hearing in the 10–20 dB range across the frequencies, responded at close to ceiling, with only a 7% difference between the initial baseline condition and the personal FM condition. Across participants, the hearing aid only and classroom infrared sound field conditions resulted in the least accurate performance (averaging 82% and 83%, respectively). Performance with the personal FM system or the desktop sound field system consistently resulted in the most accurate speech perception scores (averaging 94% in both conditions).

Although participants performed reasonably well with hearing aids alone (averaging 68%–93% correct), their performance left sufficient room for improvement. The HINT sentences have controlled language at the first-grade reading level and, therefore, did not pose much of a linguistic challenge to these academically competitive participants. When carefully inspecting Figure 1, one can see that overlap between the hearing aid alone and the classroom sound field performances in comparison to each participant's best condition (desktop or personal FM) was rare. Even Participant 5, with a baseline averaging 93%, showed improvement to 100% in the personal FM condition. Thus, there is no evidence that ceiling effects interfered with the interpretation of results. Indeed, one should not lose sight of our goal: We are trying to optimize listening in a fairly realistic classroom situation. Thus, a ceiling effect under S/N-enhancement conditions would be highly desirable.

The purpose of providing a replication condition was to observe whether the results were stable, improved with practice, or failed to maintain. Overall, it was concluded that superior performance with either personal FM or desktop systems was maintained across replication trials. This finding indicates that the superiority of results over the classroom sound field or hearing aid only conditions was reliable. Selection between the desktop and the personal FM conditions for replication might be questioned. The selection should be considered arbitrary, as the differences between these two conditions were less than 5%, with the exception of Participants 2 and 6. Like the other participants, these 2 participants continued to maintain the gains evidenced earlier when the conditions were alternated.

Participants 1, 2, and 4 demonstrated the greatest benefit from using the personal FM system. One might expect that these benefits could be accounted for by differences in perceived loudness of the setting of the personal FM versus the desktop sound field system. However, participants' subjective loudness assessment of each device using an appropriate 7-point scale did not appear to be predictive of actual benefit from any one amplification device. Indeed, neither the S/N level nor the subjective loudness was solely predictive of the results.

Children's subjective loudness ratings for devices did not necessarily coincide with the S/N ratios. For example, classroom infrared sound field and personal FM systems had similar S/N ratios, but the personal FM system was judged to be the second loudest device and the classroom sound field system was subjectively judged to be the third loudest device. The desktop sound field system had a +20 S/N, or +5 S/N greater than the other two devices. The subjective loudness of the desktop sound field system was judged to be the loudest of the three educational amplification technologies. The results of this study cannot be explained merely by consideration of the perceived intensity of the devices or the S/N provided. One key difference related to speech perception performance with different educational hearing technologies appears to be the proximity of the amplified signal within the critical listening distance.

Generalizing results to the population of children who are hard of hearing could be questioned with only 8 participants; however, robust and consistent findings across participants in single-subject experiments support generalizations to similar individuals. Furthermore, examining individual responses allows consideration of response variations to the educational amplification systems among individuals with different degrees of hearing loss.

The data from this investigation demonstrated that participants with less hearing loss did not perform as well as expected with the classroom infrared sound field system. Participant 6 had the least amount of hearing loss across the frequencies, with an aided pure-tone average of 7 dB HL. Participant 3 had a high-frequency hearing loss, resulting in an aided pure-tone average of 13 dB HL. Performance under infrared sound field conditions for both of these participants was poorer than for the other two FM systems. Under the acoustic conditions present in this study, classroom sound field technology provided insufficient S/N enhancement to benefit these experienced listeners with hearing loss. Degree of hearing loss was not a reliable predictor of the level of improvement from baseline hearing aid only performance to the best performance with either desktop sound field or personal FM systems. These results challenge the common misconceptions among audiologists that a child's performance with hearing aids in quiet or the child's degree of hearing loss can predict performance in a noisy environment.

It is important to note that the classroom used for this investigation had an RT that caused a perceptible smearing of the speech signal when the classroom sound field system was used. It is likely that performance under sound field conditions would be better in a classroom with the ANSI 2002 recommended reverberation characteristics of 0.4–0.6 s. Sound field amplification systems have been suggested as a possible amplification option for students with hearing loss ranging from mild or moderate to severe degree who use personal hearing aids (Anderson, 1989; Blair et al., 1989; Flexer, 1992), or when teachers are reluctant to use other types of educational amplification technology (Lewis, 1995). Based on the results of this investigation, providing infrared or FM sound field amplification in classrooms, specifically reverberant classrooms, to benefit students with hearing impairment appears to be unjustified.

The lack of substantial difference in performance between desktop and personal FM systems is most likely attributable to the presentation of amplified sound within the critical listening distance. It is assumed that the MicroLink personal FM device had a poorer S/N ratio than the desktop sound field device using the volume setting defined in this investigation and the compression in the MicroLink microphone/transmitter; however, the ear-level MicroLink receiver delivered the FM signal directly to the child's ears. Although the desktop sound field system may have had a greater S/N ratio than the MicroLink FM device, degradation of the speech signal occurred as it traveled from the table top to the children's eardrums. These trade-offs may have resulted in relatively equivalent speech perception with these two educational amplification technologies.

Factors Influencing Participant Performance

Although the HINT sentences have been constructed at a first-grade reading level, children with hearing loss typically have gaps in vocabulary as compared to their peers with normal hearing. Six of the 150 total sentences had somewhat more difficult vocabulary than the other sentences. These sentences were contained in 4 of the 10 sentence lists. Vocabulary that appeared to be less familiar to participants included *goal, sauce pan, match boxes, exit, cream, rancher,* and *bull.* All participants received the sentences in the same order, with the educational amplification devices randomly counterbalanced; therefore, participants had an equal chance of having these words associated with any of the three FM or infrared listening conditions. The responses for each participant were examined for performance on these six sentences. When the potential effects of vocabulary were eliminated, responses of 6 participants indicated no difference between performance on desktop and personal FM, and classroom infrared sound field technology continued to result in inferior performance. Therefore, it was concluded that vocabulary issues did not significantly alter conclusions.

Variations in performance were evident based on the participants' ability to focus on the task and their ability to use context to understand the meaning of the sentences before repeating them. The scorers observed anecdotally that the personal FM system improved listening ease over desktop or classroom infrared sound field technology. This observation seemed to be based on response latency, but no objective measure of latency was gathered. Participants listening under the personal FM condition appeared to respond more quickly and confidently than when the desktop sound field or classroom sound field systems were used. Participants also differed in their ability to cope with listening in the presence of reverberation and noise, with and without educational amplification devices. It was apparent that different listening and attention-focusing strategies of coping had an effect on the performance of at least 2 participants. Although superior performance of the personal FM over the desktop sound field system could not be concluded, it appeared evident that participants experienced less listening effort and were more confident in how clearly they perceived speech when a personal FM system was in use as compared to a desktop sound field system. This was consistent with the work of previous authors (Blake, Field, Foster, Platt, & Wertz, 1991; Flexer, Wray, & Black, 1987; Noe et al., 1997; Ross, 1981), who noted a relaxing effect and positive qualitative reports related to listening with FM delivered at ear level. A recent study found that children with hearing loss expend greater effort on listening tasks than their normally hearing peers, despite their use of personal amplification (Hicks & Tharpe, 2002). The participants in this investigation had average aided hearing ability between 7–27 dB HL and were auditory–oral learners. Even these highly capable auditory learners were found to benefit from educational amplification devices in a typically noisy and reverberant classroom.

Preference and Social Acceptance

As empirical research is performed, it is important to ascertain if the findings are indeed socially valid. The effectiveness of any result will be closely related to general appeal of the result to the population of interest (Baer & Schwartz, 1991). Optimally, social validation results will corroborate the empirical findings and support the application of the results to situations beyond controlled study conditions (Wolf, 1978). The results obtained with this social validation questionnaire were felt to reflect the satisfaction of the children in this investigation who had just experienced the various educational hearing technology devices. It is assumed that the children took their attitudes toward the appearance, sound quality, and user friendliness of the devices into account along with their performance with different devices. These differing attitudes and preferences can influence the success of use of hearing technology in the classroom. Therefore, an additional value to performing social validation in this investigation is not to determine which type of device is most popular, but instead to determine how closely the preferences for a device match an individual's performance.

On the basis of responses to the social validation instrument, it appeared that, when given the opportunity to experience or observe the use of different educational amplification technologies, most students and parents were in agreement on the devices that provided the greatest benefit. This finding can be interpreted as suggesting that the parents, through their observations of their children, were able to recognize behaviors that indicated which device provided the greatest ease and/or superior listening accuracy. When selecting which educational amplification device would be preferred by the teacher, it is possible that the children considered which device would be easiest for the teacher to use, whereas some comments by parents indicated that they made their selection with the assumption that the teacher would want to use the device that was of greatest benefit to the child.

The issue of cosmetic acceptance by classmates was addressed by the question that asked which educational amplification device the children thought class peers would think was "most cool." For this item, there was limited agreement between child and parent, suggesting that the opinion of the student might be more informed in regard to social acceptance of particular amplification devices by class peers than the opinion of parents. Two studies have reported that both adults and classmates were influenced by the size of the amplification device when making ratings on positive attributes and achievement (Danhauser, Blood, Blood, & Gomez, 1980; Dengerink & Porter, 1981).

Classroom infrared or FM sound field amplification technology is in many U.S. classrooms, both with and without mainstreamed students with hearing loss. As an educational technology that is used for all students, classroom sound field amplification can be considered the least stigmatizing of the educational amplification devices used in this investigation. It could be anticipated that the classroom sound field technology would be most acceptable to peers and, therefore, have the least negative social consequences to the students with hearing impairment. However, only 1 child and 1 parent chose the classroom sound field technology as being most acceptable to classmates. Five of the 8 student participants selected the desktop sound field device as being most acceptable by peers. This finding is positive in regard to the level of acceptance of older elementary students, who have been considered as primary users for desktop sound field systems.

Two children and 3 parents judged the ear-level personal FM device as being least acceptable to peers. It is possible that the MicroLink FM device was selected as least acceptable to classmates because it will only benefit the student with the hearing impairment, whereas the desktop sound field system will benefit students seated adjacent to the student with hearing loss and the classroom infrared sound field system will provide improved S/N ratio to all students in the classroom. It is important to recognize that the students making these judgments were all mainstreamed in regular education settings. It is possible that the perceptions of levels of acceptance of different kinds of educational amplification technology by academically and socially successful students with hearing impairment may differ from those of students who have significant learning delays. It remains critical for students to be provided with a choice of S/N-enhancing devices whenever possible. Based on the results of this investigation, it appears that providing students with a choice between desktop and personal FM will not compromise the benefits of S/N enhancement as no significant difference in performance using these two devices was apparent.

This study diverged from a dynamic and active classroom environment to provide controls over distance, noise, stimuli, presentation manner, responses, and classroom amplification use. With these variables controlled, it is possible to observe and interpret differences in speech perception associated with different educational hearing technology devices. It is important to emphasize that the results of this investigation likely show a worse case scenario for the listening performance of students with hearing loss because the background was continuous, not varying and interrupted, as is typical in a classroom environment. Also, as the teacher talks to the large group, the noise generated by students typically decreases. As the implications of the findings of this investigation are considered for practical application, individual student characteristics and the specific acoustic characteristics of the learning environment need to be considered carefully in the decision of which type of educational amplification technology should be provided.

In summary, children who have hearing impairments require the use of FM technology in their classrooms to allow them to have equal access to verbal instruction. Background noise and reverberation interfere with speech perception of children in classrooms, especially if they have hearing loss. In a noisy and reverberant classroom environment, 8 participants ages 9–12 years demonstrated no enhancement using ceiling sound field FM as compared with hearing aids alone. Benefit to speech perception was apparent when either a desktop FM system or a personal MicroLink FM receiver and personal hearing aids were used. Participants indicated on a social validation instrument that they preferred to use either the desktop or the personal FM device in this noisy and reverberant classroom listening setting. In the acoustical conditions of the typical kindergarten classroom used for this study, the infrared sound field device provided insufficient clarity of the speech signal for participants to benefit to a higher level than if they were wearing just their hearing aids. In noisy and reverberant classrooms, it appears that either the desktop or the personal FM system will provide substantial listening benefits for children with mild to moderate-severe degrees of hearing loss.

FUTURE RESEARCH NEEDS

With the advent of early identification of hearing loss in infants and appropriate early intervention services, it is probable that greater numbers of students with hearing loss will enter inclusive educational settings with normal, or near normal, educational skills. These students will require educational amplification technology to accommodate their need for equal access to verbal instruction in classrooms. Therefore, it is critical that the benefits of the different types of educational amplification technology continue to be explored so that there is a sufficient empirical basis on which to make educational hearing technology selection decisions for students who are hard of hearing.

Future research is needed to further define the effect of typical classroom acoustics on the speech perception of children with normal and impaired hearing. Systematic replication investigations are needed to explore the following variables in addition to the benefits of three S/N-enhancing devices: (a) children with greater degrees of hearing loss, (b) children using cochlear implant technology, (c) room reverberation characteristics, (d) the specific S/N ratio of different educational amplification devices used, and (e) ease of listening. First, to address ceiling effects, it is important to replicate this study with children who have greater degrees of hearing loss who are also auditory learners and are educated in inclusive classroom settings. Based on the results of this study, the 2 children with greater degrees of hearing loss performed below ceiling levels of the HINT. Ceiling effects could also be addressed by using more difficult sentence stimuli; however, this could cause a significant number of errors to be made from language issues rather than speech perception differences only. Second, including participants who are cochlear implant users would allow the determination of the most appropriate educational amplification technology to benefit the listening accuracy of mainstreamed children with cochlear implants. Third, investigation of children's performance under reverberation conditions less than 1.0 s is also warranted to determine if classroom sound field FM or infrared systems would provide benefit to children with hearing impairment over the use of their hearing aids alone if the reverberation was more acceptable (0.4–0.6 s). Fourth, the specific S/N ratios of the different types of educational amplification technology need to be measured more precisely in future studies comparing educational hearing technology devices so that this variable is clarified. Finally, a systematic evaluation of different educational amplification devices would benefit from a measure of listening effort, so that this variable can be considered in the analysis. It is suggested that the time intervals in the participant responses be recorded and compared for the different listening conditions.

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