# Benefit of S/N Enhancing Devices to Speech Perception of Children Listening in a Typical Classroom with Hearing Aids or a Cochlear Implant

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**Speech perception can be improved for children with hearing loss using signal-to-noise ratio (S/N) enhancing devices. Three experiments were performed with 28 participants, age 8 to 14 years using hearing aids or a cochlear implant. Participants repeated HINT sentence lists in classrooms with a typical level of background noise and reverberation times of either 1.1 seconds or 0.6 seconds. In addition to personal amplification, the types of devices used were a classroom sound field system, a desktop personal sound field FM system, and a personal FM system linked to hearing aids or cochlear implant.**

**The speech perception results of the three experiments support the use of a desktop or personal FM system by children with hearing loss who are auditory learners whether a poor or acceptable level of reverberation is present Based on the results of this investigation, providing classroom sound field amplification as a means to benefit speech perception of students with mild to profound bilateral hearing loss who are successful learners in the mainstream appears to be an unjustified practice for approximately 80% of students with hearing loss. Approximately 20% of participants did benefit by least 5% in word recognition score improvement from classroom sound field amplification over use of their personal devices alone. Performance scores of these participants indicated an additional 5% or greater benefit to word recognition when using desktop or personal FM as compared to their scores using classroom sound field. Results indicted that 64% of participants believed that the personal FM device provided easiest listening with either the personal FM or desktop FM being preferred for use by 26 of the 28 participants.**

Classroom learning environments typically have background noise and/or excessive room reverberation that degrade speech perception in a predictable manner (e.g., ANSI, 2002; Bradley, 1986a, b; McCroskey & Devens, 1975; Sanders, 1965). Children with hearing loss as well as hearing peers experience these problems (e.g., Bradley, 1986b; Downs & Crum, 1978; Finitzo-Hieber & Tillman, 1978; Irwin & McAuley, 1987; Neuman & Hochberg, 1983). The findings of one investigation reported that children listening in a classroom with typical levels of background noise (+6 S/N) and relatively good reverberation time (0.4 s) the children with normal hearing achieved word recogntion scores of approximately 70% as compared to 50% for students who are hard of hearing using hearing aids. When these children performed the same listening tasks in a room with higher reverberation time (1.2 s) and greater background noise levels (0 S/N) the children who were normal hearing and hard of hearing achieved scored 30% and 11%, respectively (Finitzo-Hieber & Tillman, 1978).

Children with hearing aids perceive speech in a fragmented manner due to 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). For example, a child with a moderate hearing loss in the low frequencies and a severe hearing loss in the high frequencies will typically not be able to perceive important consonant sounds like s, f, th, even when well fit hearing aids are used. Hearing aids do not restore normal hearing ability, thus, even when all speech sounds are made audible they are typically presented to the child in a speech signal that has lower intensity, or is quieter than what is perceived by peers with normal hearing. Thus children with hearing aids typically do not hear the complete speech signal and it is at lesser intensity making the speech signal even more vulnerable to degradation by the effects of distance or poor room acoustics. Hearing aids amplify both background noise and teacher's voices thus limiting the benefits of personal hearing aids worn by children in typical classroom listening environments (e.g., Nabalek, Donahue, & Letowski, 1986). Classroom noise also masks the lower intensity portions of the speech signal thereby further impairing the ability of listeners to perceive and comprehend speech (e.g., Gengel, 1971; Hawkins & Yacullo, 1984; Humes, 1991; Irwin & McAuley, 1987; Nabelek & Pickett, 1974a). Separate from the effects of background noise, reverberation in listening environments smears or distorts the speech signal (Bolt & MacDonald, 1949; Gelfand & Silman, 1979). When background noise and reverberation are both present at inappropriate levels in a classroom environment there is a synergistic effect resulting in increased degradation of speech perception above that which would be expected by a simple additive effect (e.g., Bradley, 1986b; Finitzo-Hieber & Tillman, 1978; Irwin & McAuley, 1987; Lochner & Burger, 1961; Nabelek & Pickett, 1974a,b; Yacullo & Hawkins, 1987). Distance from the speaker also degrades the speech signal and can significantly decrease speech perception (Crandell & Smaldino, 1994; Leavitt & Flexer, 1991). Hearing aids and cochlear implants have limited ability to improve speech perception if the desired speech signal that enters the microphones of these devices has degraded across listening distance, been masked by background noise, and been perceptively smeared due to excessive room reverberation. Difficulty perceiving speech under typically noisy classroom conditions has spurred the use of signal-to-noise enhancing technology for children utilizing hearing aids or cochlear implants.

The 2002 ANSI standard on acoustical performance for school classrooms has resulted in a heightened awareness of the effects of excessive background noise and reverberation on student speech perception and learning and has set criteria for defining appropriate classroom acoustics. The degradation of the speech signal within classrooms has been recognized by the audiological community for approximately 25 years and been the basis of the widespread use of educational amplification technology in schools by children with hearing loss. (Berg, 1976). The purpose of frequency modulated (FM) or infrared listening devices is to improve the signal-to-noise ratio at the listener's ear level by providing a microphone transmitter to the teacher that delivers an amplified signal through FM radio or infrared light waves to a receiver device worn by the listener. 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. Because the microphone transmitter is worn close to the teacher's mouth, this manner of amplification provides a more consistent input to the student. However, depending upon the type of receiver, the child may still have some listening challenges. Degradation of the amplified speech signal can still occur when an individual is situated beyond the critical listening distance from the loud speakers. Developments in educational amplification technology have made a variety of devices available to improve the S/N in the classroom for students with and without hearing losses in order to reduce the effects of a challenging listening environment.

The benefits of different adaptations of personal FM systems or sound field FM systems under varying classroom acoustic conditions have been examined in numerous studies (e.g., Blair, Myrup, & Viehweg, 1989; Crandell, Charlton, Kinder, & Kreisman, 2001; Crandell, Holmes, Flexer, & Payne, 1998; Flexer, Richards, Buie, & Brandy, 1994; Foster, Brackett, Maxon, 1997; Hanin & Adams, 1996; Sarff, Ray, & Bagwell, 1981). A S/N of +15 or better is recognized as being necessary to assure that noise will not be a barrier to learning within a classroom (ANSI Standard, 2002). In addition to a highly favorable S/N, studies have indicated that the child with hearing loss also requires the primary signal to be presented within the critical distance for listening (Picard & Lefrancois, 1986, Crandell, Holmes, Flexer, & Payne, 1998).

When close to the talker, the direct speech signal and early reflections of sound predominate and are beneficial to accurate speech perception. As the talker and the listener become farther apart, early and late reverberation predominates. The point in a room at which the intensity of the direct sound is equal to the intensity of the reverberant sound is called the critical distance. Early and late reverberation beyond the critical distance for listening mask portions of the speech signal causing a smearing effect to the accurate perception of speech. Background noise can interfere in accurate speech perception at any distance but has a greater negative affect to speech perception when combined with the effects of reverberation occurring beyond the critical distance. The use of personal or desk top FM devices artificially assures that the listener remains within the critical distance for listening, regardless of the size of the room or distance from the talker using the microphone transmitter. When a classroom has both a teacher producing a direct signal and loudspeakers from which sound field amplification is produced, there are multiple direct sources of sound but the critical listening distance remains a factor in speech perception. Although the sound is amplified throughout the room, the listener is not artificially assured of being within the critical distance for listening as he or she would be if the direct sound was at ear level or on a desk top. Therefore, listeners have been found to consistently perceive speech better when ear-level or desktop personal sound field FM devices (hereafter called desktop FM) are used. This is true for hearing individuals (Nabelek & Donahue, 1986; Nabelek, Donahue, & Letowski, 1986; Smith, McConnel, Walter, & Miller, 1985; Blake, Field, Foster, Platt, & Wertz, 1991). It is also true for persons who are hearing aid users (Picard & Lefrancois, 1986; Blair, Myrup & Viehweg, 1989; Moeller, Donaghy, Beuchaine, Lewis, & Stelmachowicz, 1996; Noe, Davidson, & Mishler, 1997; Boothroyd & Iglehart, 1998; Noe, 1999; Anderson & Goldstein, 2004; Anderson, Goldstein, Colodzin, & Iglehart, 2003) or cochlear implant users (Foster, Brackett, & Maxon, 1997; Crandell, Holmes, Flexer, & Payne, 1998).

Classrooms that meet ANSI standards have a reverberation time that is a minimum of 0.4 – 0.6 s and an unoccupied noise level in the classroom of no more than 35 dBA in order to achieve a recommended +15 dB S/N (ANSI, 2002). Under these acoustic conditions, the use of an ear level FM system has demonstrated an improvement in word recognition of approximately 20% (Picard & Lefrancois, 1986) for individuals with hearing loss with word recognition ability in quiet of at least 40%-60% (Boothroyd & Iglehart, 1998). Under classroom reverberation conditions that have a 0.3s reverberation time which is ideal for speech perception, an increase of up to 25% improvement in word recognition has been found to occur (Boothroyd & Iglehart, 1998).

Persons using a cochlear implant need a minimum of +10 S/N to function appropriately (Fetterman & Domico, 2002) but require at least a +15 S/N if they are to be expected to access verbal instruction (Hamzavi, Franz, Baumgartner, & Gstoettner, 2001), even in a classroom that meets the ANSI acoustic standards. An improvement of approximately 15-20% in word recognition scores may be achieved in +15 S/N conditions compared to +10 S/N (Hamzavi, Franz, Baumgartner, & Gstoettner, 2001). Enhancement to S/N provided by a desktop FM device can improve word recognition scores by approximately 20% (Foster, Brackett, & Maxon, 1997). Positive benefits using sound field amplification have been found in classrooms having very low reverberation time (Blair et al., 1989; Noe et al. 1997; Iglehart, 2003). Even in a low reverberation environment, performance has been found to be better with devices when the signal is presented within the critical listening distance than through sound field FM or infrared devices presenting the teacher's voice throughout the classroom (Nabelek & Donahue, 1986; Nabelek et al., 1986; Noe et al., 1997).

In summary, children with hearing loss require special consideration of their listening needs in a classroom setting if they are to be able to access verbal instruction as fully as possible within the limitations of their hearing limitations. Further research was needed to consider the performance of children with hearing aids or cochlear implants in a variety of acoustic conditions when listening with educational amplification technology that is in current use in classrooms. There were five objectives to this series of experiments: (1) to investigate the speech recognition abilities of children using hearing aids or a cochlear implant when they listen under typical classroom noise and reverberation conditions. (2) to investigate the effects of three types of S/N enhancing technology on the speech recognition abilities of these same children (wall-mounted sound field infrared amplification system, sound field loudspeaker placed on the student's desk, and personal FM system with direct audio input into each child's hearing aid or cochlear implant. (3) to investigate the opinions of participants regarding which FM system was preferred under these controlled, comparative conditions. (4) to investigate these same three objectives with participants of varying levels of hearing loss ranging from mild to profound that use either hearing aids or a cochlear implant. (5) to investigate these objectives in a classroom with relatively poor acoustic conditions and in a classroom with relatively good acoustic conditions.

## Method

### Participants

A total of 28 individuals participated over the course of three experiments. These participants exhibited a range of hearing loss from mild to moderate to profoundly deaf. All participants had received amplification at a young age and were consistent amplification users, accustomed to listening with optimally fit amplification. All functioned within the classroom as hard of hearing students. No participants required manual communication support (i.e., sign language) to access verbal instruction in the educational setting. Participants in Experiments 1 and 2 were from the same large suburban school district, attended general education classrooms and did not receive special education instruction. Participants in Experiment 3 were from an oral school environment with small class sizes and intensive educational experiences. School documents indicated that all participants had normal intelligence, language abilities within one-year of their age peers, and did not have identified disabilities other than hearing loss. All participants had speech intelligibility sufficient to allow them to be understood by adult listeners who were familiar with typical articulation patterns of children who are hard of hearing.

*Experiment 1.* Eight children between the ages of 9 and 12 who had a congenital hearing loss of mild to severe degree participated in this study. Hearing ability ranged from normal hearing to a moderate degree of hearing loss in the low frequencies sloping to mild to severe degree above 1000 Hz. All participants had aided speech reception thresholds under sound field conditions that were within the normal hearing to mild hearing loss range. The hearing aids of seven of the eight participants were removed and replaced with Phonak Novoforte 3 programmable analog devices that had been adjusted to meet their specific needs. The remaining participant used Widex C19 digital hearing aids for school listening. Age, hearing loss, and amplification information of participants is included in Table 1.

*Experiment 2.* Participants consisted of nine children between 8 and 14 years of age who had congenital hearing losses that were greater than those in Experiment 1. These children had hearing losses of moderate to moderate-severe degree with hearing ability of no worse than 90 dB HL 250Hz - 4000Hz, as evidenced on an audiogram performed less than 12 months prior to the date of investigation. Hearing loss information for participants in Experiment 2 can be found on Table 2.

**Table 1. Age and hearing threshoold information for nine participants in Experiment 1.**

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

*Experiment 3.* Participants in Experiment 3 consisted of eleven children between the ages of 8 years, 11 months to 12 years, 11 months. Five had moderate to severe degrees of hearing loss and wore their own personal hearing aids. Six participants had severe to profound hearing loss and used monaural cochlear implants. Participant hearing loss information for Experiment 3 can be found on Table 3. Amplification devices used in all three experiments did not have directional microphones.

**Setting**

*Listening Environments.* Experiments 1 and 2 were performed in a typical kindergarten classroom listening environment. The room dimensions were 11.9 x 7.6 by 2.7 m with an additional 2.4 x 5.2 m of open shelves and coat cubby area. The volume of the room was 244.2 $m^3$ consisting of 90.4 $m^2$ of carpeted area, and 140.2 $m^2$ of linoleum floor covering. During these investigations, the participants were seated at a small table on the linoleum where student tables were typically placed.

A performance arts classroom was the setting for Experiment 3. This room was chosen due to noise and reverberation characteristics representative of a classroom listening environment with relatively good acoustic conditions. The classroom dimensions were 14.6 x 7.6 x 3.7 m, with a volume of 410.6 $m^3$, with 52.0 $m^2$ of carpeted area, and 59.5 $m^2$ of polished wood flooring. Participants sat near the middle of the carpet where student tables were typically placed.

*Room Set-Up.* For Experiments 1 and 2, a "simulated teacher", comprised of a compact disc player on top of an Omni Petite sound field loudspeaker, was set up 1.7 m in front of the blackboard and 3.4 m from the wall parallel to the front wall. The height of the center of the loudspeaker was 1.4 m from the floor to simulate a teacher instructing from a standing position in the front of a classroom. The speech stimulus averaged 83 dBA at 8.9 cm from the center of the Omni Petite sound field speaker. This distance was selected to represent the preferred distance for microphones to be worn from a teacher's mouth (Crandell & Smaldino, 1994). Participants were seated directly in front of the Omni Petite sound source at a distance of 3 m.

In Experiment 3 the "simulated teacher" represented by a compact disc player, this time connected to a Roland MA -12C monitor with a self-contained amplifier. The "simulated teacher" was located in the front of the carpeted area of the classroom. As in Experiments 1 and 2, the center of the loudspeaker was 1.4 m from the floor and participants were seated 3 m directly in front of the "simulated teacher". All other distances, seating position, and set up of the amplification equipment replicated Experiment 1. Both the Omni Petite and the Roland loudspeakers were selected because they were designed for accurate representation of the speech signal across the frequency spectrum.

The speech stimulus was measured at the typical participant

**Table 2. Age and hearing threshold information for nine participants in Experiment 2.**

| Child | Age | Ear | 250 Hz | 500 Hz | 1000 Hz | 2000 Hz | 4000 Hz | 8000 Hz | PTA |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 9y 10m | R | 50 | 70 | 85 | 80 | 75 | 60 | 78 |
| | | L | 50 | 60 | 85 | 80 | 70 | 65 | 75 |
| | | Aided | 10 | 15 | 30 | 35 | 20 | | 27 |
| 2 | 10y 3m | R | 50 | 50 | 65 | 65 | 65 | 75 | 60 |
| | | L | 30 | 40 | 65 | 60 | 65 | 90 | 57 |
| | | Aided | | 25 | 20 | 30 | 35 | | 25 |
| 3 | 10y 3m | R | 5 | 10 | 20 | 70 | 90 | 85 | 33 |
| | | L | 5 | 5 | 30 | 65 | 80 | 85 | 33 |
| | | Aided | | 10 | 10 | 20 | 40 | | 13 |
| 4 | 9y 2m | R | 20 | 55 | 70 | 90 | 65 | 105 | 72 |
| | | L | 25 | 60 | 70 | 60 | 60 | 80 | 63 |
| | | Aided | | 25 | 25 | 20 | 20 | | 23 |
| 5 | 11y 5m | R | 4 | 35 | 40 | 45 | 45 | 65 | 40 |
| | | L | 55 | 50 | 60 | 65 | 65 | 70 | 58 |
| | | Aided | 10 | 10 | 15 | 20 | 20 | | 15 |
| 6 | 9y 7m | R | 15 | 25 | 40 | 50 | 55 | 70 | 38 |
| | | L | 20 | 25 | 45 | 45 | 55 | 70 | 38 |
| | | Aided | | 5 | 5 | 10 | 15 | | 7 |
| 7 | 10y 2m | R | 35 | 30 | 50 | 55 | 60 | 70 | 47 |
| | | L | 30 | 30 | 55 | 60 | 65 | 70 | 47 |
| | | Aided | | 20 | 20 | 25 | 30 | | 22 |
| 8 | 11y 11m | R | 60 | 65 | 85 | 75 | 70 | 85 | 75 |
| | | L | 55 | 55 | 85 | 70 | 75 | 105 | 70 |
| | | Aided | | 30 | 25 | 25 | 40 | | 27 |
| 9 | 9y 0m | R | 40 | 50 | 85 | 75 | 105 | NR | 70 |
| | | L | 45 | 55 | 75 | 80 | 65 | 75 | 70 |
| | | Aided | | 25 | 20 | 20 | 30 | | 22 |

head position with a Quest 2700 sound level meter. Speech stimuli were set to have a constant intensity of 70 dBA SPL in Experiment 1 and 66 dBA SPL in Experiment 2. In Experiment 3, a Larson Davis System 824 sound level meter was used to measure the speech stimulus that was presented at 56 dBA SPL at the approximate ear level of the participants.

In Experiments 1 and 2, were conducted in a real kindergarten classroom that had a classroom sound field amplification system installed and in use for daily teaching. The 1.1s reverberation time present in the classroom was relatively high but not unusual for a kindergarten classroom. A 60 dBA background noise source with a +10 speech signal (70 dBA) was present. Because of the size of the classroom and the reflection caused by the linoleum flooring the reverberation level in this class required the sound level settings for speech and amplified sound to be higher than what was necessary in the classroom used in Experiment 3, which had relatively good reverberation and noise characteristics. Through participant report, the speech signal was perceived as being somewhat louder than necessary in Experiment 1 but was loud enough to be perceived clearly over the effects of reverberation and was the actual setting used by the kindergarten teacher. It was also believed important to provide a S/N that could be a realistic representation of a noisy and reverberant classroom environment. In Experiment 2, a somewhat lower speech signal level (66 dBA, +6 S/N) was used. This decrease was felt to be as much of a decrease as possible while still allowing perception of speech in the classroom.

*Background noise.* Background noise is any sound that is unrelated to the speech that is the desired signal. Typical classrooms have an ambient noise level ranging from 53 to 74 dB SPL with those in public school classrooms averaging 60 dB SPL (Maxon & Brackett, 1978; Olsen, 1977). The S/N of a classroom is determined by subtracting the intensity of the primary speech signal from the intensity of the background noise. Using a Quest 2700 sound level meter in Experiment 1 and 2, the classroom ventilation fan was audibly circulating air during all data collection producing a sound pressure level of 54 dBA at the participant's ear level. This noise level was less than the 60 dB SPL average (Maxon & Brackett, 1978; Olsen, 1977), therefore, hospital cafeteria noise was presented from an audio cassette player at a 45º angle, 3.65 m behind and to the left of the participant listening position in Experiments 1 and 2 and directly behind in Experiment 3 Hospital cafeteria noise incorporates voice babble and random noise clatter - extraneous sound sources that are commonly present in classrooms. Using a digital

**Table 3. Characteristics of participants in Experiment 3.**

| Participant | Age HL First Suspected | Age at Test (Years)* | Age at Implantation (Years) | CI Processor | HA Model | Hearing Loss R | (dBHL) L |
|---|---|---|---|---|---|---|---|
| 1 | Birth | 12.1 | 11.3 | 3G | | CI | 110 |
| 2 | Birth | 13.0 | 9.7 | SPrint | | 93 | CI |
| 4 | Birth | 6.9 | 4.9 | 3G | | 100 | CI |
| 5 | 13 M | 11.6 | 7.0 | SPrint | | CI | 105 |
| 8 | 5M | 12.6 | 9.3 | ESPrit | | CI | 95 |
| 10 | 11M | 12.5 | approx. 2yrs.** | ESPrit | | CI | 103 |
| 3 | 1-2 Y | 9.6 | | | DigiFocusCompact | 70 | 76 |
| 6 | 2 Y | 10.8 | | | PicoForte PPSC | 81 | 93 |
| 7 | Birth | 10.2 | | | Phonak E4 | 80 | 78 |
| 9 | 12 M | 10.9 | | | Phonak E4 | 78 | 83 |
| 11 | 15 M | 9.0 | | | Phonak E4 | 83 | 73 |

* The number to the right of the decimal is a fraction of a year, not numbers of months
** Reimplanted at age 6 years due to device failure.

speech processor to clip the intensity peaks, the cafeteria noise was modified so that it had a spectral shape that is similar to multitalker babble, which has a spectral shape similar to the background noises common in everyday educational situations (Crandell & Smaldino, 1994).

The intensity of the cafeteria noise in combination with the ventilation fan in Experiment 1 was at a constant level of 60 dBA, which was 10 dB less intense than the 70 dBA SPL speech stimulus (+ 10 dB S/N). In Experiment 2, the audiocassette player producing the hospital cafeteria noise was placed in the same location in the classroom as in Experiment 1. The intensity of the constant ventilation fan and the cafeteria noise was again 60 dBA with a 66 dBA speech stimulus resulting in a S/N of +6 dB. In Experiment 3, the ventilation noise was minimal in comparison to the classroom used for Experiments 1 and 2. The intensity of the cafeteria noise was a constant 46 dBA, and the speech stimulus was 56 dBA SPL (+10 dB S/N). The noise in Experiment 3 was directly behind the listeners rather than at 45º behind and to the left as it was for Experiments 1 and 2, because in the previous studies the participants had been binaural amplification users. If the noise had been presented at 45º behind and to the left as it had in Experiments 1 and 2, the listeners with cochlear implants on their left ears would have been at a greater disadvantage than those with cochlear implants on their right ears.

*Reverberation.* Reverberation time is defined as that 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 audible smearing of speech sounds and the negative effect on speech perception. Typical RT in unoccupied classrooms ranges from 0.5-1.2 s (Crandell & Smaldino, 1994). In Experiments 1 and 2, the RT was determined using a Goldline GL-60 Reverb Time Meter at the participant's seating position. Per manual instructions for the Goldline GL-60, a sound source was introduced and RT was measured using the –15 dB SPL reference point at 2000 Hz. Stability was achieved at this setting, thus allowing other frequencies to be reliably measured. The average of RT at 500, 1000, 2000 Hz was estimated at 1.1 s. 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 0.35 to 1.2 s (Crandell & Smaldino, 1994). Thus, the classroom used for Experiments 1 and 2 was at the higher end of the typical RT range.

A Larson Davis System 824 sound level meter was in Experiment 3 used to measure RT by following the manufacturer's recommendations for determining RT 60. At the participant's head position the RT was: 250 Hz, 0.70s; 500 Hz, 0.70s; 1000 Hz, 0.58s; 2000 Hz 0.52s; and 4000 Hz, 0.38s, averaging 0.60s for 500, 1000, and 2000 Hz. This RT was within the recommendation of the ANSI 2002 Standards for Acoustics in Educational Settings.

*Hearing Aids and Cochlear Implants.* Seven of the eight participants in Experiment 1 wore Novo Forte 3 hearing aids that had been programmed specifically to meet auditory targets of each individual participant. The hearing aids were worn by the students at school to allow them to use MicroLink ML7 personal FM receivers via direct audio input and to allow students to change frequency modules as they move between different teaching environments. NovoForte hearing aids include a choice of linear and non-linear signal processing strategies and highly flexible filtering but do not have directional microphones.

The goal in fitting amplification is to make the long-term average speech spectrum available throughout the frequency range so that speech sounds can be perceived. Using a NOAH platform computer program, the Novo Forte 3 hearing aids were programmed according to manufacturer's program specifications to identify National Acoustics Laboratories (NAL) targets to match individual participant's audiometric profiles. Participant 4 was an exception in that personal Widex C19 digital hearing aids (noise control circuit was not activated) were used with the MLX FM receivers. Electroacoustic testing of all hearing aids in Experiments 1 and 2 using a Fonix 500 electroacoustic analyzer and real ear testing had been performed on all participants using these hearing aids four to five days prior to the data collection date to reduce the level of fatigue of participants on the day of data collection. In Experiment 2, all participants wore NovoForte 3 hearing aids that were individually programmed to match audibility targets as described above.

Participants in Experiment 3 wore a variety of hearing instruments. The only individual using digital hearing instruments was participant 3 who used Oticon DigiFocus Compact instruments. Participants 7, 9 and 11 each used Phonak NovoForte E4 instruments. Participant 6 used Phonak Pico Forte PPSC instruments. Thus, of the five participants in Experiment 3 who were hearing aid users, four had analog instruments. The hearing aids were adjusted to manufacturer's recommended settings based on each participant's audiometric data. If the participant showed poorer-than-expected perception of high-frequency speech sounds (e.g., /s/ and /t/) the gain and output settings in the frequencies above 1000 Hz were increased slightly above manufacturer's recommended settings if comfortable and acceptable to the participant.

A Frye Electronics Inc. Fonix 6500 CX Hearing Aid Test System was used to test hearing aids in Experiment 3 prior to the test sessions using ANSI procedures and verifying that the instruments met the respective manufacturer's specifications.

The six participants who were cochlear implant users had Nucleus 24 devices. Age of implantation is specified in Table 3. Sprint speech processors were used by participants 2 and 5, 3G speech processors by participants 1 and 4, and participants 8 and 10 used ESPrit speech processors.

**Amplification Systems**

A loudspeaker representing the teacher delivered the speech stimuli to a microphone transmitter placed 8.9 cm from the loudspeaker. Two different types of FM systems and an infrared sound field system with wall-mounted loudspeakers were used to enhance the S/N within the classroom setting, each on a different frequency. In Experiments 1 and 2 the loudspeaker used to simulate the teacher was an Omni Petite sound field system. In Experiment 3 a Roland MA -12C monitor with a self-contained amplifier was used. These loudspeakers were designed with the purpose of high fidelity reproduction of the speech signal.

The devices selected to enhance S/N were of recent manufacture and in widespread use in classrooms. This 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 of any particular system for this study should not be construed as endorsement of certain manufacturer's equipment, as there are multiple devices available that fulfill the same function at essentially the same quality.

Prior to data collection, participants identified the loudness level of their hearing aids or cochlear implant and each of the S/N enhancing devices with the assistance of a pictorial 7-point loudness chart. The descriptive words in order of loudest (7) to quietest (1) were: hurts, too loud, a little bit loud, just right, a little bit soft, too soft, nothing. When a structured age-appropriate protocol is used, children ages 4 to 7 years old have been found to make relatively accurate loudness judgments (Kawell, Kopun, & Stelmachowicz, 1988). Participants listened to practice sentences and were then asked to choose the number on the loudness scale that represented their perception of the loudness of each device. This was done in order to ensure that the devices were not uncomfortably loud and provided a means by which subjective loudness could be used to explain individual differences in performance with the S/N enhancing devices.

*Classroom sound field system.* The classroom sound field FM system used in Experiments 1 and 2 was a TeachLogic IR-2500 receiver and loudspeaker system with a TeachLogic IRB-10 infrared wireless transmitter. Two speakers were mounted at the juncture of the ceiling and wall at approximately 60º and 240º from the position of the participant's seat when facing 0º azimuth to the Omni Petite loudspeaker used to present speech stimuli. The 1.1 s reverberation time present in this classroom was a challenge for setting the loudness of the infrared sound field system within the recommended 10 – 15 dB amplification of the teacher's voice typical of this technology (Lewis, 1995). The amplification effect was imperceptible as a listening benefit from the participant's seating position due to the high reverberation time of the classroom when the device was set at +10 dB S/N. Therefore a loudness setting of 75 dBA, or +15 dB S/N was selected.

The classroom sound field system in Experiment 3 was a Phonic Ear PE 900R Vocalight system that transmitted the speech signal by infrared to a receiver powering four speakers mounted near the ceiling. The placement of the loudspeakers was approximately at 2 o'clock, 4 o'clock, 8 o'clock and 10 o'clock relative to a participant facing the "teacher" speaker. The loudness was set just below the threshold of acoustic feedback, resulting in a speech signal presented by the Vocalight system at 61 dBA SPL or +15 S/N.

If the loudspeakers were placed at a distance that was either closer to or farther away from the participant's seat or if they were placed in a different configuration in the classroom the S/N could be different at the ear level of the participant. Loudspeaker placement must be tailored to the shape, size, student position, typical teaching position, background noise source, and the reverberant features of each classroom.

*Personal sound field system (desktop).* The desktop sound field FM system used in all three experiments was a LES 390 Desktop SoundPak manufactured by LightSpeed Technologies that was taped into position at 0º azimuth, 35.6 cm from the table edge closest to the participant. It 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 LES 390 has a top-mounted volume control that is highly variable. The level of background noise in the classroom is taken into account as the appropriate volume level is identified so that the signal is still audible to the target student but the volume of the desktop FM is not uncomfortable for surrounding normal-hearing students. In these studies two normal-hearing adult listeners agreed upon an appropriate level to provide comfortable listening over the reverberation and the multitalker background noise, but also at a level that would not be likely to interfere with class dynamics. In Experiment 1 the desktop FM volume control was set at an intensity of 80 dBA, which was +20 S/N louder than background noise. In Experiment 2 the desktop FM volume was set at78 dBA, which was +18 S/N and in Experiment 3 the desktop FM was set with a 66 dBA volume, which was +20 S/N.

*Personal FM system (MicroLink).* In Experiments 1 and 2 Phonak MicroLink ML7 ear-level receivers and an ML4 transmitter were used. A MLx receiver with a TX2 transmitter was used in Experiment 3. Hearing aid and MicroLink receiver settings were adjusted according to the FM manufacturer's guide (Phonak, 2001). The MicroLink ML7 and MLx personal FM receivers were linked via direct audio input to personal hearing aids that had been individually programmed and verified through real ear measurements. The auditory targets of each participant were met according to the respective hearing-aid manufacturer's software for FM-plus-microphone input, with no other changes in the hearing aid programming.

Participants using a cochlear implant wore a Phonak MLCI+ receiver and a MicroLink TX2 transmitter. The input cords used with the MLCI+ receivers were appropriate to the different speech processors as specified in Phonak manual "MLCI/MLCI+ Reference Guide for Cochlear Implant Wearers" (Phonak, 2003). The manufacturers' fitting protocols (Julie Reichert, Cochlear Americas, personal communication, March, 2003; Phonak, 2003) were followed with some modifications. The gain setting on the FM receiver was adjusted in a sound-resistant booth in quiet according to protocol with speech presentation at 55 dB HL. When noise ("speech noise" produced by a Grason-Stadler GSI 61 Clinical Audiometer) at 45 dBHL was introduced modification to the fitting protocol was necessary. The speech noise was annoying to one participant resulting in the gain setting on the FM receiver was reduced. Another participant was annoyed by speech noise to the point that the speech noise in the sound booth had to be reduced to 40 dB HL before proceeding with setting the FM gain. When presented with hospital cafeteria noise in the test classroom, two different participants requested that the gain on the FM receiver be increased above the level selected earlier in the booth.

The compression threshold of the MicroLink microphone/transmitter is exceeded and the signal is compressed when an input exceeds 70 dB SPL. It was estimated that the signal-to-noise ratio of the MicroLink personal FM was +14 (personal communication Phonak, August, 2002).

**S/N Determination**

An objective of Experiment 3 was to determine the S/N levels in a manner that was more objective than the standard sound level survey technique that was used in Experiments 1 and 2. Sound level measurements were determined by performing a survey of the levels of speech stimuli and noise under different conditions. A Larson Davis System 824 was used for Leq (A) measurements using the same test sentence ("The broom is in the corner.") across listening conditions. Noise was measured for 6 s, a duration sufficient for the Leq measurement to stabilize on the meter.

The following procedure was developed to obtain the S/Ns with a hearing aid in use. Using a Frye HA2 (2cc) coupler placed on the Larson Davis System 824 one-half inch microphone, an unvented earmold with a standard bore was attached to the coupler using putty clinically developed for such purposes. A Phonak NovoForte E4 behind-the-ear hearing aid was attached to the earmold and the aid was set with gain at 66 dB SPL, L full on at #8, LNH set to N, H full on at #7, and peak clipping full on at #7. Only Phonak NovoForte E4 hearing aid was used to determine S/N as there was no objective in this investigation to determine S/N provided by all hearing aids. An assumption was made that if the child's hearing aids were fit appropriately to meet his or her listening needs (per RECD and DSL hearing fitting strategies) that the improvement in intensity level provided by S/N enhancing devices would be relatively equivalent across hearing aids. The MicroLink FM system was coupled to the hearing aid, using an audioshoe and the settings recommended by the FM manufacturer (Phonak, 2001). The hearing aid was adjusted for microphone-plus-FM input, with no other programming changes made. The hearing aid, attached to this apparatus, was held at ear-level position at the participant's seat in the test classroom for purposes of these output measurements. Using this set up, the aided sound level of noise was 96 dBA and the level of the speech stimulus was 101 dBA, resulting in +5 dB S/N. Using the infrared sound field system the aided speech level was 103 dBA, resulting in +7 S/N. Using the desktop FM the resulting aided speech level was 108 dBA, resulting in +12 S/N. The MicroLink FM provided an aided speech level of 110 dBA, resulting in +14 S/N. Personal hearing aids with differing processing capabilities and settings will produce differing S/N when tested under these same conditions.

**Speech Stimuli**

The loudspeaker used as a "simulated teacher" produced speech stimuli averaging 83 dBA. The three transmitter microphones for the FM systems were placed on a music stand and held in the same spatial plane in relation to the loudspeaker. A loudness of 83 dBA has been reported to be representative of typical teacher presentation levels (Crandell & Smaldino, 1994). The transmitters were switched on and off according to a predetermined order of FM presentation that was different for each participant.

Sentences were selected to simulate listening to connected speech in verbal instruction as closely as possible, while controlling for possible gaps in language that often occur in children who have hearing loss. Participants in all three experiments were required to verbally repeat sentences from the Hearing In Noise Test (HINT). 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 was modified at the House Ear Institute in Los Angeles (1996) using vocabulary typical of English speakers in the United States. 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; 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, 1987). All test sentences were presented only once during data collection. Recording of the selected HINT lists was performed by a female in a sound treated environment using monitored live voice 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 for each of the four listening device conditions. Fifteen additional HINT sentences were recorded as practice sentences. Three practice sentences were presented prior to each HINT sentence list to familiarize the participants with listening to each test condition.

**Experimental Design and Conditions**

Per previously described changes in S/N level and reverberation time, and the change from a baseline and replication trial in Experiments 1 and 2 to four fully randomized listening conditions in Experiment 3, the experimental design was not held consistent in all ways across the three experiments, thus preventing a combined statistical analysis of data. The design of the experiment was modified based on experience with each prior study. The test protocols (speech and noise stimuli, recording sheets) and procedures (distances, average decibel levels, determination of volume control placement on instruments) were held consistent across the three experiments thus allowing the results of the three studies to be considered collectively. The variables of reverberation time and participant hearing loss or hearing aids versus cochlear implant use were modified to expand and strengthen the results so that any common findings could be generalized to a larger population of children who are functionally hard of hearing.

A single subject investigation with an alternating treatments design was used for the first two experiments. This type of experimental design specifies the administration of stimuli in different treatment conditions with the order of the treatments randomized across participants (Kazden, 1982). The alternating treatments design was used to examine whether consistent differences in speech recognition were evident for each participant in the four listening conditions. Experimental control was evaluated by presenting at least three HINT lists for hearing aids only and for each of the three listening conditions using the S/N enhancing devices.

The presentation of 15 practice HINT sentences was followed by initial baseline testing. Baseline testing consisted of presenting three HINT sentence lists of 10 sentences each with participants using only their hearing aids to amplify the speech signal. Following completion of the 30 baseline sentences, each participant was required to listen to and repeat three HINT sentence lists per FM condition. The participants wore hearing aids during all FM conditions. All sentence lists were presented in the same order. The sequence of when each experimental condition was presented was counterbalanced across the participants. The three FM amplification conditions were presented in 9 sentence lists. Three practice sentences were presented when each amplification condition was introduced to allow participants to adjust to the level of attention and effort required for listening to each of the FM devices prior to the introduction of test sentences. Once testing began, no repetition of any of the 10 test sentences occurred. A brief break occurred after every three sentence lists.

As is customary in single subjects alternating treatment designs, the listening condition that provided greatest benefit to each individual was identified and was continued for three more HINT lists in Experiment 1 and 2 to determine whether performance remained stable under that condition. The decision of which FM system resulted in superior performance was determined by adding up the three scores for each of the FM systems, averaging them, and selecting the FM system with the best performance averaged across the three word lists. Accuracy in sentence repetition had to differ by a mean of at least one additional word correct to qualify as superior performance. One participant in Experiment 1 did not have at least a one word correct average advantage in performance for any single listening condition therefore, the hearing aid only condition was repeated.

The experimental design for Experiment 3 differed somewhat from Experiments 1 and 2. In Experiment 3 the personal amplification (hearing aids or cochlear implant) only condition was not performed first for all participants (baseline). The order of presentation of the personal amplification only sentence lists was randomized along with the lists used to evaluate the educational amplification technology. Also, there were no replication trials. Thus, the four experimental conditions were compared using a repeated measures design with the order of the four treatment conditions counterbalanced across participants. During Experiment 3, 12 lists (120 sentences) were presented as compared to the 150 sentences repeated in Experiments 1 and 2 when a replication trial was performed

**Scoring Participant Responses**

Participant responses were rated independently by two individuals who had extensive experience in providing services to children who are hard of hearing. Scoring for all three experiments was based on the number of words repeated correctly in each sentence. 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. The same response sheets specifying allowable errors were used for all three experiments. Brief breaks were provided after every three HINT lists. During breaks the raters totaled the number of words spoken correctly for each list.

**Social Validation**

A measure of social validity was administered to determine how well participant preferences for S/N enhancing devices agreed with their performance with the different devices. Following completion of the experimental conditions, each participant was asked about his or her preference of amplification conditions using the following simple questions: (1) Which FM did you find easiest to listen to? (2) Which FM do you think your teacher would most like to use? (3) Which FM do you think your classmates would find most cool? (4) Which FM would you like to use most in your classroom? (5) Which FM would you not like to use in your classroom, if given a choice? The five questions were written at a Flesch-Kincaid reading level of grade 2.1, so that the questions were simple for all of the participants (grades 3-7) to comprehend.

**Results**

**Reliability**

In Experiment 1 and 2 there were fifteen word lists each with 50 words, for a possible total correct of 750 words per participant. In Experiment 3 there were 12 word lists each with 50 words, for a possible total correct of 600 words per participant. Interobserver agreement was calculated for 100% of the data by dividing the number of word agreements by the total agreements plus disagreements and multiplied by 100. Interobserver agreement was calculated for 100% of the data. The overall interobserver agreement in Experiment 1 was 99.1%. Interobserver agreement was 99.0% in Experiment 2 and was 98.8% for Experiment 3.

**Perceived Loudness**

Participant report of perceived loudness was via a 7-point pictorial scale, with 7 representing loudest and number one representing the quietest. Thus, a response of 4 on this scale would be considered to be in the most comfortable loudness for listening. The mean responses for all 28 participants for each device were as follows: hearing aids only 3.9; classroom sound field 4.4; desktop FM 4.6; personal FM 4.2.

**Word Recognition Performance**

Table 4 provides a summary of the mean accuracy of participant responses per condition. The mean accuracy response data was considered for all three experiments with three main findings. First, there appears to be no significant difference in the performance associated with the use of classroom sound field amplification over the use of hearing aids or cochlear implants alone. Second, the data indicated a consistent benefit to using desktop and personal FM systems over the use of hearing aids alone. A third main finding was that there was no significant difference between the degree of benefit provided by the desktop FM system, as compared to the personal FM system. These findings are not attributable to the perceived loudness of the different devices. Statistical analysis was not performed for Experiment 1 data due to the single subject design of the experiments. The conclusions drawn from examining single subject data graphs (refer to Anderson & Goldstein, 2004) resulted in the same conclusions as were evident in Experiments 2 and 3. Experiment 1 mean results were as follows: hearing aid only 82.4%, classroom sound field 83.1%, desktop FM 93.5%, and personal FM 94.4%. It is worth noting though that Participants 5 performed at 93% or above across all conditions, therefore demonstrating little or no advantage when using S/N enhancing devices over hearing aids alone.

A one way repeated measures analysis of variance was performed for Experiment 2 data. The analysis revealed a significant difference among conditions [$F(3, 24) = 8.65$, $p < .001$, partial eta squared = 0.52]. To isolate the types of amplification technology that differed from the others, a Holm-Sidak multiple comparison procedure was used. Three main group findings were identified that were consistent with the findings stated above. As can be seen in Table 4, participants averaged 87.3% and 88% correct speech perception with hearing aids alone and the classroom sound field device, respectively. Speech recognition improvement resulted in a mean score of 92.4% for desktop FM and 92.6% for personal FM systems. Participants 1, 4, and 7 performed at 92% or above across all conditions, therefore demonstrating little or no advantage when using S/N enhancing devices over their hearing aids alone.

An analysis of Experiment 3 data was also performed. A two-way analysis of variance, with one between-subject variable (two personal devices) and repeated measures (four listening conditions) was conducted. The main effect for device [$F(1, 9) = 0.62$, $p > .05$, partial eta squared = 0.06] and the device x condition interaction [$F(3, 27) = 0.65$, $p > .05$] were not significant. A significant effect for the listening conditions was revealed [$F(3, 27) = 23.25$, $p < .001$, partial eta squared = .72]. To isolate the types of amplification technology that differed from the others, once again, a Holm-Sidak multiple comparison procedure was used. Pairwise multiple comparisons resulted in the three main findings that had been established in Experiments 1 and 2. For the population of children studied there appeared to be no enhancement in performance associated with the use of ceiling sound field amplification over the use of hearing aids alone ($p = 0.630$), nor for the children with cochlear implants ($p = 0.460$). Individually, out of 11 participants, only one child with a cochlear implant and two children with hearing aids had higher speech perception scores using classroom sound field amplification over personal devices alone and, of these three, all performed substantially better using desktop and/or personal FM than with classroom sound field.

Of the 28 participants, 11 had higher scores using classroom sound field over their personal devices alone, however only four of these had greater than 5% enhancement in performance and all performed between 12% to 32% better using desktop and/or personal FM.

One result that is not able to be supported by speech perception performance is the observation that participants appeared to have a greater ease of listening when using the personal FM system over other devices. Participants appeared to respond more quickly and with less effort when using the personal FM device. Randomization of different sentences across listening conditions prevented meaningful comparison of time delay of responses to be obtained.

**Social Validation Results**

The results of the social validation measure for all 28 participants were as follows: Easiest Listening: 18 chose personal FM, 9 desktop FM, 1 classroom sound field; Teacher Preference: 15 personal FM, 5 desktop FM, 8 classroom sound field; Highest Classmate Acceptance: 10 personal FM, 11 desktop FM, 7 classroom sound field; Most Desired S/N Device: 21 personal FM, 5 desktop FM, 2 classroom amplification; Least Desired S/N Device: 2 personal FM, 12 desktop FM; 15 classroom sound field.

In summary, personal FM was chosen by the majority of all 28 participants as being the easiest to listen to, the most preferred by teachers, the most desired S/N enhancing device, and almost equivalent with desktop FM for most acceptable by classmates. Of the 28 participants, 64.3% found the personal FM easiest

**Table 4. Percent correct responses for participants listening to HINT sentences for hearing aid users (HA) and cochlear implant users (CI).**

| Exp # | Part. # | Personal Device | Personal Device only | Classroom SF Infrared | Desktop FM | Personl FM |
|---|---|---|---|---|---|---|
| 1 | 1 | HA | 68.0 | 74.6 | 84.0 | 86.7 |
| 1 | 2 | HA | 76.0 | 71.3 | 86.7 | 95.3 |
| 1 | 3 | HA | 80.6 | 82.0 | 92.0 | 95.3 |
| 1 | 4 | HA | 89.3 | 84.0 | 92.7 | 96.7 |
| 1 | 5 | HA | 93.3 | 95.3 | 98.7 | 100.0 |
| 1 | 6 | HA | 88.7 | 82.0 | 97.3 | 89.3 |
| 1 | 7 | HA | 90.7 | 93.3 | 99.3 | 97.3 |
| 1 | 8 | HA | 72.7 | 82.0 | 97.3 | 94.7 |
| **mean** | | **HA** | **82.4** | **83.1** | **93.5** | **94.4** |
| 2 | 1 | HA | 95.7 | 95.7 | 92.0 | 92.4 |
| 2 | 2 | HA | 89.0 | 88.3 | 97.0 | 99.3 |
| 2 | 3 | HA | 82.7 | 79.3 | 87.0 | 88.3 |
| 2 | 4 | HA | 98.0 | 96.3 | 97.7 | 98.0 |
| 2 | 5 | HA | 90.3 | 91.0 | 94.7 | 92.0 |
| 2 | 6 | HA | 72.7 | 75.7 | 85.0 | 81.0 |
| 2 | 7 | HA | 92.7 | 92.0 | 94.0 | 96.0 |
| 2 | 8 | HA | 73.2 | 88.3 | 94.7 | 92.3 |
| 2 | 9 | HA | 91.0 | 85.0 | 89.3 | 94.3 |
| **mean** | | **HA** | **87.3** | **88.0** | **92.4** | **92.6** |
| 3 | 1 | CI | 72.0 | 74.2 | 94.0 | 92.0 |
| 3 | 2 | CI | 86.0. | 72.0 | 90.0 | 84.0 |
| 3 | 3 | HA | 96.0 | 82.0 | 92.0 | 100.0 |
| 3 | 4 | CI | 95.0 | 84.0 | 100.0 | 100.0 |
| 3 | 5 | CI | 79.9 | 30.0 | 60.0 | 76.0 |
| 3 | 6 | HA | 46.0 | 50.0 | 78.0 | 82.0 |
| 3 | 7 | HA | 68.0 | 92.0 | 86.0 | 100.0 |
| 3 | 8 | CI | 46.0 | 62.0 | 84.0 | 100.0 |
| 3 | 9 | HA | 90.0 | 80.0 | 96.0 | 92.0 |
| 3 | 10 | CI | 86.0 | 68.0 | 96.0 | 92.0 |
| 3 | 11 | HA | 90.0 | 76.0 | 88.0 | 92.0 |
| **mean** | | **HA/CI** | **77.7** | **70.0** | **87.6** | **91.8** |
| **mean** | | **HA only** | **78.0** | **76.0** | **88.0** | **93.2** |
| **mean** | | **CI only** | **77.5** | **65.0** | **87.3** | **90.7** |
| | | **Total Mean** | **82.13** | **79.51** | **90.83** | **92.82** |
| | | **Standard Deviation** | **13.55** | **14.46** | **8.18** | **6.33** |

to listen to, with 32.1% choosing desk top and only 3.6% of participants choosing classroom sound field as being the easiest of the three S/N devices for listening. This finding provides some substantiation of the observed ease of listening that personal FM provided over the other S/N enhancing devices. Participants perceived that teachers would prefer to use classroom sound field to desktop FM (28.6% to 17.9%), but personal FM was perceived as the most preferred of the three devices (53.6%). Perception of classmate acceptance was 39% for desktop FM, 35% for personal FM, and only 24% of participants indicating that their classmates would be most accepting of classroom sound field. Three-fourths, or 75% of participants preferred to use personal FM in their classrooms over the other two devices. Of the remaining 25% of participants,, 18% preferred desktop FM and 7% selected classroom sound field as their preferred choice. Finally, 54% of participants did not want classroom sound field, 43% did not want desktop FM, and only 7% did not want to use personal FM in their daily classroom environment.

## Discussion

### Benefit of S/N Enhancing Devices

Generalizing results to the population of children who are hard of hearing could be questioned with only 28 participants, however, robust and consistent findings across participants, designs, and acoustic variables support generalizations to similar individuals. The speech perception results of these three experiments support the use of a desktop or personal FM system by children with hearing loss who are auditory learners in typically noisy and reverberant classroom listening environments. The use of sound field amplification with speakers placed adjacent to the classroom ceiling in classrooms generally provided little or no benefit to speech perception performance over the use of hearing aids or the use of a cochlear implant alone for most participants.

Regardless of the advancements in hearing aids and cochlear implants, digital sound processing or programmable technology cannot overcome the effects of background noise or reverberation on speech perception. Neither the S/N level nor the subjective loudness was solely predictive of the results. It appears that presentation of amplified speech within the critical listening distance is an important key factor in addition to a S/N of at least +15.

Across participants the hearing aid/cochlear implant only and classroom sound field amplification conditions resulted in the least accurate performance whereas performance with either the personal FM system or the desktop FM consistently resulted in the most accurate speech perception. It must be noted that one participant four (14.3%) participants had 5% or greater improvements in performance when using classroom sound field technology , however they all performed better with either desktop or personal FM than with classroom sound field amplification. Six participants (21.4%) had baseline, or personal device only, scores greater than 92%, thus allowing little room for the benefit of S/N enhancement to be illustrated. Of these six participants, four had improved scores using desktop or personal FM and two did not have observable benefit using S/N enhancing technology.

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, Myrup, & Viehweg, 1989) or when teachers are reluctant to use other types of educational amplification technology (Lewis, 1995). Although it may be assumed that children with lesser degrees of hearing loss would benefit from classroom sound field amplification more than children with greater degrees of hearing loss, the data from this investigation did not support that assumption here. Performance under classroom infrared sound field conditions for participants with mild to moderate degrees of hearing loss was poorer than for the two FM systems. Under the acoustic conditions present in this study, classroom sound field technology provided insufficient S/N enhancement to benefit the majority of these experienced listeners with hearing loss. Therefore, 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 FM or personal FM. These results challenge the common misconceptions among audiologists and teachers of the deaf and hard of hearing that performance with hearing aids in quiet or degree of hearing loss can predict performance in a noisy environment.

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, Myrup, & Viehweg, 1989) or when teachers are reluctant to use other types of educational amplification technology (Lewis, 1995). Based on the results of this investigation, providing classroom sound field amplification as a means to benefit the speech perception of students with hearing impairment appears to be an unjustified practice for approximately 80% of students with hearing loss who are successful learners in the mainstream. Indeed, 7 of 28 participants (25%) had at least 10% better performance with their personal device as compared to classroom sound field, 1 participant (3.6%) had performance that was between 5-10% better when listening only with a personal device, 15 (53.6%) had equal performance or within 5% difference, 2 participants (7.1%) had between 5-10% improvement with classroom sound field and an additional 3 (10.7%) of participants responded with scores that were 10% or greater when classroom sound field was used as compared with their personal devices. Of the approximately 20% (5 participants) who did benefit from classroom sound field amplification over use of their personal devices alone, 3 participants scored an additional 12% or greater using desktop FM or personal FM over the scores for classroom sound field technology, and the other 2 participants scored an additional 5-10% higher using desktop FM or personal FM as compared to their scores using classroom sound field. Thus, although there are some students who could benefit from classroom sound field technology, our findings indicate that increased levels of benefit would occur for most students with the use of personal FM or desktop FM technology. It must be noted that four participants had speech perception scores of greater than 95% when using personal devices alone, and of this number two showed no improvement with S/N enhancing devices and two improved to 100% using either the desktop FM or personal FM. On the social validation measure three of these participants indicated that personal FM provided easiest listening and the other indicated desktop FM was provided easiest listening.

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. The lack of substantial difference in performance between desktop and personal FM systems is most likely attributable to both devices presenting a S/N benefit of approximately +15 S/N or greater and the presentation of amplified sound within the critical listening distance of the individual. Although the desktop FM may have had a greater S/N than the Microlink FM device, degradation of the speech signal occurred as it traveled from the table top to the children's eardrums. These tradeoffs may have resulted in relatively equivalent speech perception with these two educational amplification technologies.

**Preference and Social Acceptance**

As empirical research is performed, it is important to ascertain if the findings are 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 importance of the empirical research findings, thus suggesting that the results also can be applicable to situations beyond controlled study conditions (Wolf, 1978). The results obtained on the social validation questionnaire seemed to reflect children's satisfaction with the various educational hearing technology devices that yielded superior speech recognition. It is assumed that the children took into account their attitudes toward the appearance, sound quality, and user-friendliness of the devices along with their performance with each. These varying attitudes and preferences can influence the successful use of hearing technology in the classroom. Therefore, an additional value to performing social validation assessments is to determine how closely the preferences for a device match an individual's performance, as well as popularity of devices.

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 with those FM devices that provided the greatest benefit. 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 (e.g., Danhauser, Blood, Blood, & Gomez, 1980; Dengerink & Porter, 1981).

It is important to recognize that students making preference judgments were all mainstreamed and competitive 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 loss may differ from those students who have significant learning delays. It remains critical for students to be provided a choice of S/N enhancing devices whenever possible. Based on the results of this investigation, it appears that providing students 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. For the four students who evidenced benefit from classroom sound field use, only the individual that performed best with this device preferred it for classroom use, although this same child indicated that the easiest listening was provided by the desktop FM. The other three individuals that evidenced benefit using sound field technology that was within 3% of FM devices indicated easiest listening and classroom preference for use of either desktop or personal FM. Therefore, although classroom sound field technology may be of some benefit to approximately 15% of the population of functionally hard of hearing students, this technology does not appear to provide the ease of listening of other devices and is generally not preferred by experienced auditory performers listening in typical classroom acoustic conditions.

**Conclusion**

In a typically noisy and reverberant classroom, the use of state of the art digital or programmable analog hearing aids by listeners who were hard of hearing is not sufficient to overcome acoustic degradation of the speech signal, thus necessitating S/N enhancing devices to allow most of these students to have equal access to verbal instruction in the classroom setting. Over 80% of the 28 students (8-14 years old) demonstrated no enhancement using classroom sound field technology as compared to hearing aids or cochlear implant use alone as indicated by scores that were equivalent or less than 5% different from personal device use. Of the remaining almost 20% (5 participants) that evidenced 10% or greater benefit from the use of classroom sound field technology over their personal devices, 3 participants had an additional 12% or greater benefit over classroom sound field when either personal FM or desktop FM was used and the remaining 2 participants evidenced between 5%-10% additional benefit. Thus, for the majority of participants the greatest benefit to speech perception was apparent when either a desktop FM system or a personal MicroLink FM receiver and personal hearing aids or cochlear implants were used. Participants indicated on a social validation instrument that they preferred to use either the desktop or personal FM device in the experimental classroom listening setting. Almost two-thirds of participants rated the personal FM as providing the greatest ease of listening. The classroom sound field system provided insufficient clarity of the speech signal for most participants to benefit more than if they were wearing just their hearing aids or cochlear implant. In typically noisy and reverberant classrooms, it appears that either the desktop or personal FM system will provide substantial listening benefit of varying degree for children who are functionally hard of hearing.

Children with hearing loss require use of FM technology in their classrooms to allow them to have equal access to verbal instruction. Hearing aids or cochlear implants alone, even those with recent technological advances, do not overcome the interfering effects of background noise and reverberation on speech perception of children in classrooms. This study diverged from a dynamic and active classroom environment to provide controls over distance, noise, stimuli, presentation manner, responses, and FM use. With these variables controlled it is possible to observe and interpret differences in speech perception associated with different educational hearing technology devices.

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 when deciding which type of educational amplification technology should be provided. 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 provide 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 sufficient empirical basis upon which to make FM device selection decisions for students with hearing loss who are auditory learners.

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