# Spatial Hearing in Noise of Young Children with Cochlear Implants and Hearing Aids

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**The primary goals of this investigation were (1) to determine the sensitivity of the Phrases in Noise Test (PINT) for identifying children with hearing loss who were at risk for educational difficulties in the classroom, (2) to examine the effects of spatial location of the speech and noise sources on the speech recognition in noise of participants using bilateral cochlear implants (CIs), bilateral hearing aids, or a CI on one ear and hearing aid on the non-implant ear (bimodal stimulation), and (3) to determine the relationship between teacher ratings of educational risk and speech recognition in noise. Twenty-nine children using bilateral CIs, bilateral hearing aids, or bimodal stimulation were tested with the PINT in conditions with speech and noise from the same location or from separate locations in a small room. Teachers of the participants were asked to complete the Preschool Screening Instrument for Targeting Educational Risk (S.I.F.T.E.R.). Average results from the three groups of children suggest significant spatial release from masking, where the spatial separation of speech and noise sources resulted in improved speech-in-noise thresholds. Several medium and strong negative correlations were calculated, where poorer speech-in-noise thresholds on the PINT were related significantly to at-risk Preschool S.I.F.T.E.R. ratings from teachers. In comparison to PINT performance in age-matched children with normal-hearing sensitivity from a previous study, 93% of children in the present study have significantly poorer PINT thresholds. A combination of the PINT and the Preschool S.I.F.T.E.R. may be used by educational audiologists to identify young children with hearing loss who have educational need for classroom accommodations and hearing assistance technology.**

## Introduction

### Factors Influencing Children's Speech Recognition

In a typical classroom environment, students with hearing aids and cochlear implants (CIs) experience considerable difficulty hearing and comprehending teachers and classmates because of the room acoustics, competing background noise, effects of age, and presence of hearing loss. Typical classrooms do not provide ideal listening or learning situations for any child due to the excessive unoccupied and occupied noise levels, long reverberation times, and poor signal-to-noise ratios (SNR; Arnold & Canning, 1999; Knecht, Nelson, & Whitelaw, 2002; Sanders, 1965). In fact, previous research suggested that few classrooms met the current recommendations of the American Speech-Language-Hearing Association (ASHA) for unoccupied noise levels and reverberation times (ASHA, 2005; Knecht et al., 2002). When occupied, classrooms with poor acoustics are likely to pose an even greater hearing challenge due to the fluctuating background noise levels throughout the day. The background noise level in a classroom fluctuates because of various classroom activities (lecture, group work), use of classroom equipment (computers, projectors, cycling ventilation systems), sources outside the classroom (hallways, other classrooms), and teacher movement around the room during instruction.

Younger children ($\leq$ 5 to 6 years) are at an even greater disadvantage than older children and adults in classrooms with poor acoustics because there is a developmental effect associated with speech recognition performance in the presence of background noise (Papso & Blood, 1989; Litovsky, 2005; Jamieson, Kranic, & Yu, 2004; Johnstone & Litovsky, 2006; Neuman, Wroblewsi, Hajicek, & Rubinstein, 2010; Schafer et al.,in press). For example, Jamieson and colleagues (2004) reported that 5- to 6-year-old children with normal-hearing sensitivity (Mean 74-76%) had significantly poorer speech recognition in classroom noise at a -6 SNR than 7- to 8-year-old children (Mean 97-95%). These age-related differences may be attributed to numerous factors, some of which include maturation, cognition, language comprehension, and working memory (Montgomery, 2008; Magimairaj & Montgomery, 2012; Montgomery, Magimairaj, & O'Malley, 2008).

The age of the child may also influence speech recognition in noise when the speech and noise are presented from different spatial locations. In a recent study in our laboratory (Schafer et al., in press), we reported significantly poorer speech recognition performance in four-classroom noise for a group of 3-year olds with normal-hearing sensitivity as compared to groups of 4-, 5-, and 6-year olds. In addition, 3-, 4-, and 5-year olds had significantly poorer speech recognition in noise than adults. In this study, the largest age differences occurred in a condition with speech and noise presented from the same spatial location (S0/N0) as compared to a condition with spatially-separated speech and noise sources (S0/N180), which is often referred to as a spatial release from masking (SRM). Therefore, the difficulty of a speech-recognition-in-noise task may be related to the location of the speech and noise stimuli, with spatially coincident stimuli (S0/N0) resulting in the most challenging listening situation.

The investigators' definition of SRM is the difference in dB between conditions with speech and noise from the same loudspeaker (S0/N0) versus speech and noise from different loudspeakers (most typically S0/N90). SRM is influenced by all factors contributing to speech recognition in noise, some of which include the child's speech reception threshold in quiet, background noise level at threshold, developmental level, auditory working memory, language comprehension, auditory attention, and binaural auditory processing ability. Therefore, the measurements of a child's thresholds in noise as well as SRM provide audiologists a tool that may be used to assess a broad range of functional capabilities in the auditory domain. Furthermore, measuring SRM in children with hearing loss is critical because it supports the need for (1) preferential seating near the teacher in typical classrooms, (2) directional microphone technologies in hearing aids and CIs, and (3) hearing assistance technology (HAT), such as frequency modulation (FM) systems.

According to previous investigations, the presence of SRM, as measured in S0/N0 and S0/N90 conditions, in children with hearing aids and CIs is variable. For example, in one study that included children with bilateral CIs and bimodal stimulation, significant SRM of 5.2 dB was found when noise was shifted from the front (S0/N0) to the side of the second CI or hearing aid (S0/N90), but an SRM of only 1.8 dB was reported when noise was shifted from the front to the side of the first or only CI (Litovsky, Johnstone, & Godar, 2006). However, in another study including children with bilateral CIs and similar test conditions, children achieved significant SRM with noise shifts to both sides (Van Deun, van Wieringen, & Wouters, 2010). Similar to the Litovsky et al. (2006) study, a comparison of SRM between the conditions with noise presented to the first CI (1.6 dB) versus noise presented to the second CI (-4 dB) yielded significant larger SRM with noise to the second CI (Van Deun et al., 2010). Finally, in a study on children with hearing aids, the authors reported no significant SRM for word (0.63 dB) or sentence stimuli (0.17 dB) presented in a S0/N0 condition versus a condition with simultaneous noise from two loudspeakers at + 90 degrees azimuth (Ching, Wanrooy, Dillon, & Carter, 2011). Given the variability across these three studies, and the importance of SRM for children with hearing loss, additional research on SRM in children with hearing aids and CIs is warranted.

Adding to the challenges from the combined effects of typical classroom acoustics and age is the presence of sensorineural hearing loss. For example, an early comparison study between children with normal-hearing sensitivity and children with hearing loss suggested significantly poorer speech recognition for the children with hearing loss by up to 85% in conditions with increasing noise and reverberation times relative to peers in an ideal listening situation (Finitzo-Hieber & Tillman, 1987). In CIs, advances in front-end processing, sound processing strategies, directional microphones, and use of bilateral CIs and bimodal stimulation as compared to a unilateral CI have significantly improved speech recognition of children and adults with CIs (Ching, 2000; Schafer, Amlani, Seibold, & Shattuck, 2007; Schafer, Amlani, Paiva, Nozari, & Verrett, 2011; Wolfe, Schafer, John, & Hudson, 2011; Wolfe et al., 2012), but these users continue to experience significantly decreased speech recognition performance in the presence of background noise and reverberation as compared to conditions in quiet or to normal-hearing peers (Schafer & Thibodeau, 2004; Stickney, Assman, Chang, & Zeng, 2007). Specifically, when compared to quiet listening conditions, speech recognition of children and adults with CIs decreased by up to 45% in the presence of background noise (Firszt et al., 2004; Schafer & Thibodeau, 2003, 2004). Users of hearing aids have also experienced significant benefit from improved technology, such as frequency compression and directional microphones (Auriemmo et al., 2009; Wolfe et al., 2011), but similar to users of CIs, children and adults with hearing aids show significant decreases in speech recognition in noise on the order of 40% relative to a quiet condition (Auriemmo et al., 2009) or to peers with normal-hearing sensitivity (Scollie, 2008). Reasons for the poorer performance in noise of children with CIs and HAs is likely related to numerous factors, but most importantly, CIs and hearing aids cannot completely separate the primary speech signal from the competing background noise (i.e., poor SNRs), and these devices cannot restore normal auditory function.

**Importance of Assessing Speech Recognition**

Determining the combined effects of classroom acoustics, competing background noise, age, and hearing loss on a child's speech recognition performance is critical for educational audiologists who will need to identify and quantify educational need. Educational need as it relates to hearing loss, which the authors define as significantly poorer performance in one or more area of assessment (e.g., speech recognition, communication, listening behavior, etc.) than normal-hearing peers, is often a prerequisite to special education services or purchase of HAT, especially for children who are functioning on grade level and are educated in general education classrooms. Furthermore, speech recognition testing may be used to document benefit of HAT, over a CI or a hearing aid alone, after it is fit on a child (American Academy of Audiology, 2008). Therefore, assessments of speech recognition performance in noise and educational need are important for all school-aged students with hearing loss, which also includes preschool-aged children from 3 to 6 years.

At this time, there are few sensitive speech perception measures specifically designed for testing in noise that are also appropriate for young children (see Schafer, 2010 for a review). The few tests that are commercially available are not designed for use in noise, contain higher-level vocabulary, or may result in ceiling and floor effects (0% or 100%) from percent-correct scoring. For example, commonly used pediatric tests, such as the Word Intelligibility by Picture Identification (WIPI; Cienkowski, Ross, & Lerman, 2009; Ross & Lerman, 1970; Ross, Lerman, & Cienkowski, 2004) and the Northwestern University-Children's Perception of Speech Test (NU-CHIPS; Elliott & Katz, 1980), do not have equivalent word lists in the presence of background noise (Chermak, Pederson, & Bendel, 1984; Chermak, Wagner, & Bendel, 1988). The pediatric speech recognition tests that are designed for use in noise, such as the Hearing in Noise Test for Children (HINT-C; Nilsson, Soli, & Sullivan, 1994) or the Bamford-Kowal-Bench Speech-in-Noise test (BKB-SIN; Etymotic Research, 2005) have vocabulary levels that exceed that of a typical 5-year old child. Finally, the one test that is designed for young children and for use in noise, the Pediatric Speech Intelligibility test (PSI; Jerger & Jerger, 1982, 1984), may result in ceiling and floor effects or the need to administer multiple lists to find the most appropriate SNR for each child in order to avoid these effects. Unfortunately, young children may not have the attention spans necessary to complete multiple PSI speech recognition lists at different SNRs. Also, the single-talker competitor used for this test may not replicate the type of multi-source noise encountered in typical classrooms.

**Rationale for Investigation**

Given the need for a sensitive speech recognition test in noise for young children, the goals of this study are (1) to determine the sensitivity of a newly-developed measure, the Phrases in Noise Test (PINT), for identifying children with CIs and/or hearing aids who are at risk for educational difficulties in the classroom; (2) to examine the effects of spatial location of the speech and noise sources (SRM) on the speech recognition in noise of the participants using bilateral CIs, bilateral hearing aids, or a CI on one ear and hearing aid on the non-implant ear (bimodal stimulation); (3) to examine and to compare the relationship between teacher ratings of educational risk to the children's speech recognition in noise.

The PINT estimates a child's speech-in-noise threshold at the 50% correct level and requires the child to act out the speech stimuli with a stuffed animal or doll. The PINT stimuli include 12 simple phrases (Table 2) and four-classroom noise that ascends and descends in intensity. This test paradigm is similar to the one used by the creators of the BKB-SIN test (Etymotic Research, 2005), where a range of SNRs are pre-recorded on a compact disc (CD). The PINT task has slightly higher auditory complexity than simple word identification because it requires the child to detect the phrase (or word), recognize the phrase, and carry out the associated action (i.e., follow instructions). Also, because this test requires an action from the child instead of a verbal response, the presence of articulation problems, which may influence the child's speech intelligibility to an examiner, does not influence the reliability of examiner scoring.

Although the PINT has been used in previous investigations to assess speech-in-noise thresholds in young children with normal-hearing sensitivity or CIs (Schafer & Thibodeau, 2006; Schafer et al., in press), the sensitivity of the test for identifying children who have educational need for services in the schools has yet to be determined. Individual results of the children in the present study may be compared to PINT data from children with normal-hearing sensitivity in a previous investigation (Schafer et al., in press) to determine a child's level of performance relative to peers. In addition, unlike previous investigations of SRM in children with hearing loss (e.g., Ching et al., 2011; Litovsky et al., 2006; Van Deun et al., 2010), the listening conditions included in this study will (1) investigate the presence of SRM in three different populations of young children using binaural listening arrangements, (2) use the same speech recognition measure (PINT) with each population, and (3) utilize a different noise loudspeaker location for conditions with spatially-separated speech and noise sources (S0/N180 used instead of the S0/N90 configuration used in previous investigations). Overall, the children with hearing loss are expected to perform worse than children with normal-hearing sensitivity in a previous investigation (Schafer et al., in press), which will support the sensitivity of the PINT for the detecting speech recognition difficulty in background noise as compared to peers. Additionally, performance on the PINT will be compared to teacher ratings on a screening tool to examine children's levels of educational risk as compared to peers. The examiners hypothesize that strong correlations will be calculated between the teacher ratings on the screening instrument and speech recognition in noise performance on the PINT.

## Methods

### Participants

A total of 29 children, ages 2;8 to 7;3 years, were included in this investigation. The children were using bilateral CIs (n=13), bilateral hearing aids (n=10), or bimodal stimulation (n=6). In order to participate, children had to act out all 12 PINT phrases in a quiet condition with 100% accuracy after familiarization. Children that could not complete this task were dismissed from the study. All children had spoken English as a first language, had no history of recurrent otitis media (defined as more than six occurrences), and had no cognitive issues via parent report on a case history form. All children were receiving special education services or other private speech-language therapy. With the exception of three children using bilateral hearing aids (Subjects 21-23) and one child using bimodal stimulation (Subject 25), participants were enrolled in Auditory-Verbal Therapy with a certified Listening and Spoken Language Specialist (LSLS). Children were enrolled in one of the following educational placements: private oral school for students with hearing impairment (n=8), public preschool or elementary school (n=10), mainstreamed private school (n=8), home school (n=2), and Head Start program (n=1). Specific information about the ages, devices, and duration of device use for the participants is provided in Table 1. The average unaided audiogram for the bilateral hearing aid group is provided in Figure 1. The investigators were unable to obtain unaided audiograms for the non-implant ear of all the children in the bimodal group, but audiograms of three participants reveal a moderately-severe-to-severe (Subject 25), severe-to-profound (Subject 26), and mild-to-severe (Subject 27) sensorineural hearing loss in the non-implant ear. (See Table 1 page 10)

The examiners aimed to replicate the most likely listening condition used during a school day; therefore, during testing, children were using their normal, everyday settings on their hearing aids and CIs. The parents reported that these settings were used at school. The hearing aids worn by the children may have utilized adaptive noise reduction programs and directional microphones; however, some audiologist may have deactivated these features. Use of directional microphones in an environment with spatial separation of speech and noise sources could significantly improve a child's speech recognition in noise by 3 to 7 dB relative to their performance or other children's performance without directional microphones in the same condition (Amlani, 2001; Auriemmo et al., 2009). To our knowledge, there is no strong evidence to support noise reduction strategies in children. However, there is some evidence that use of noise reduction improves listening comfort and the acceptable noise levels of adults with hearing aids (Mueller & Bentler, 2005).

Several of the children in the bilateral hearing aid group (n=6) and bimodal group (n=5) utilized hearing aids with frequency compression (i.e., Phonak Naida and Nios shown in Table 1). After a period of at least six months of use, instruments with frequency compression may have provided the subjects with bilateral hearing aids significantly improved speech recognition in quiet and in noise due to the improved audibility of high-frequency speech sounds (Glista, Scollie, & Sulkers, in press; Wolfe et al., 2011). There is limited evidence regarding the benefit of frequency compression for users of the bimodal arrangement. Although, one study suggested that, while the bimodal arrangement was beneficial relative to the CI alone, use of the frequency compression algorithm did not result in better performance than a hearing aid with no frequency compression (Park, Teagle, Buss, Roush, & Buchman, in press). Prior to speech recognition testing, all hearing aids used by participants were tested in a hearing aid test box (AudioScan Verifit) using the American National Standards Institute standard criteria (ANSI S.3.22-2003) to verify functioning. In hearing aids employing frequency compression, the frequency compression (i.e., limited high-frequency gain) was always visible to the examiner in the ANSI test and was used by all participants with Phonak Nios or Naida hearing aids (Table 1).

Regarding signal processing for the children with CIs, the investigators believe that it is highly unlikely that any of the children with CIs were using a noise program as his or her most common

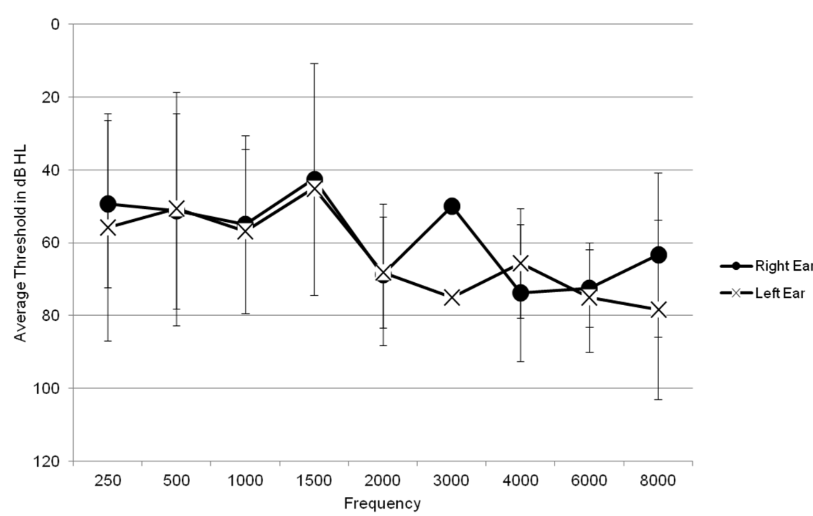


**Figure 1**. Unaided thresholds of the participants in the bilateral hearing aid group.

**Table 1**. Participant Information

| | Subject | Age | CI Sound Processor(s) | HA Make/Model | Duration 1st CI | Duration 1st HA | Duration Binaural Use |
|---|---|---|---|---|---|---|---|
| Bilateral Cochlear Implant Group | 1 | 6;5 | Freedom | . | 3;2 | 0;2 | 4;3 |
| | 2 | 6;11 | Freedom | . | 5;8 | 0;7 | 5;9 |
| | 3 | 6;8 | Nucleus 5 | . | 5;2 | 5;0 | 0;2 |
| | 4 | 6;11 | OPUS 2 | . | 5;4 | . | 5;2 |
| | 5 | 4;5 | OPUS 2 | . | 3;3 | 0;7 | 3;5 |
| | 6 | 4;0 | OPUS 2 | . | 2;3 | 0;3 | 2;4 |
| | 7 | 2;10 | Nucleus 5 | . | 1;10 | 1;1 | 1;6 |
| | 8 | 6;4 | OPUS 2 | . | 1;0 | 5;6 | 1;0 |
| | 9 | 4;5 | Harmony | . | 3;7 | 0;3 | 3;7 |
| | 10 | 4;1 | Freedom | . | 2;0 | 1;0 | 2;0 |
| | 11 | 4;7 | Freedom | . | 3;0 | 0;3 | 3;1 |
| | 12 | 4;10 | Freedom | . | 2;8 | 2;0 | 2;10 |
| | 13 | 4;0 | Freedom | . | 2;6 | 0;2 | 2;6 |
| | **Average** | **5;0** | . | . | **3;2** | **1;4** | **3;3** |
| Bilateral Hearing Aid Group | 14 | 6;2 | . | Phonak Maxx 311 Forte | . | 3;7 | 3;7 |
| | 15 | 3;11 | . | Phonak Naida | . | 0;11 | 0;11 |
| | 16 | 6;7 | . | Phonak Naida | . | 4;9 | 4;9 |
| | 17 | 6;4 | . | Oticon Sumo DM | . | 4;0 | 4;0 |
| | 18 | 4;4 | . | Phonak Naida III SP BTE | . | 3;7 | 3;7 |
| | 19 | 6;6 | . | Phonak Naida V SP Junior | . | 2;0 | 2;0 |
| | 20 | 6;0 | . | Phonak Nios micro | . | 4;0 | 4;0 |
| | 21 | 7;3 | . | Phonak Nios micro | . | 1;11 | 1;11 |
| | 22 | 3;10 | . | Phonak Nios micro | . | 1;11 | 1;11 |
| | 23 | 6;1 | . | Starkey Destiny 1200 | . | . | . |
| | **Average** | **5;6** | . | . | . | **2;11** | **2;11** |
| Bimodal Stimulation Group | 24 | 4;10 | OPUS 2 | Phonak Nios III | 1;3 | 2;0 | 1;3 |
| | 25 | 6;8 | Freedom | Phonak Maxx 311 Forte | 1;7 | 3;8 | 1;7 |
| | 26 | 4;6 | Nucleus 5 | Phonak Naida III SP | 1;6 | 4;3 | 1;6 |
| | 27 | 3;4 | OPUS 2 | Phonak Naida III SP | 1;0 | 2;1 | 1;0 |
| | 28 | 3;8 | OPUS 2 | Phonak Naida | 1;11 | 3;2 | 1;11 |
| | 29 | 3;3 | OPUS 2 | Phonak Naida | 2;1 | 3;1 | 2;1 |
| | **Average** | **4;4** | . | . | **1;7** | **3;0** | **1;7** |

Note. CI=cochlear implant; Ages and durations of use are in years and months; dot represents not applicable or unknown.

setting. However, if a child was using a noise program, such as the noise program in Cochlear processors containing Autosensitivity (ASC) and Adaptive Dynamic Range Optimization (ADRO), their performance in noise would be enhanced relative to performance with their everyday program (Wolfe et al., 2011). Specific fitting algorithms or methods to program the CIs were not available to the investigators because the children were fit at various centers and clinics. Functioning of each separate CI worn by a child was verified through a behavioral listening check, which consisted of the examiner asking the child to repeat words or sounds with no visual cues.

The reader should note that the exact settings used by the children with hearing aids and CIs were unknown to the examiners, and the potential impact of these technologies were not within the scope of the present investigation. Therefore, the reader should exercise caution when attempting to relate any of the findings in this study directly to one or more technologies that were or were not enabled in the children's hearing aids or CIs.

**Test Rooms and Equipment**

Testing was conducted in several small rooms where the children were seen for audiological services and/or speech-language therapy. Real rooms, rather than sound booths, were used to ensure that results represented speech recognition performance in an environment with acoustics that are more commonly encountered by children with hearing loss. Testing was conducted in a total of six different rooms. Within each group, bilateral CI participants were tested in a total of five different rooms, bilateral hearing aid participants were tested in two rooms, and bimodal stimulation participants were tested in four rooms. In each room, participants were seated at a small table in the middle of the room. Although testing in a single room would have been preferable to the investigators, the sample sizes in each group would have been severely limited. The examiners had to travel up to four hours to test some of these participants.

The use of multiple rooms for testing was not expected to influence the results of the study because the acoustics varied only slightly across the rooms. Specifically, with the exception of one room where only one bimodal participant was tested, all rooms met the ANSI (2010) and ASHA (2005) recommendations for unoccupied noise levels (< 35 dBA) and reverberation times (< 0.6s) in classrooms. The single room that did not meet the ASHA and ANSI recommendations had an average unoccupied noise level of 42.0 dBA across eight measurements around the room. This higher noise level was not expected to negatively influence performance because the PINT is conducted in the presence of background noise, and the calibration procedure for the PINT accounts for unoccupied noise levels. This same room also had the longest reverberation time of any room in the study (0.4 s); however, this room met the ASHA recommendation for classroom reverberation. In addition, previous research suggests that an increasing reverberation time from 0.3 to 0.6 seconds only results in a change in speech recognition performance by an average of 1 dB (SD approximately .5 dB) in six-year-old children (Neuman, Wroblewski, Hajicek, & Rubinstein, 2010). Therefore, given the 3-dB step size of the PINT stimuli, and the narrow range of reverberation times measured for the rooms in this study (0.3 to 0.4 seconds), differing reverberation times would not be expected to contribute to any variation in the thresholds-in-noise across participants within each group.

The speech and noise stimuli were presented via CD with a Sony CD-Radio-Cassette-Corder (Sony CFD-ZW755), two detachable, single-coned loudspeakers, and additional speaker wire. The loudspeakers were 3 feet from the listener at head level and were placed at 0 and 180 degrees azimuth relative to the listener. Stimuli intensities were calibrated using a calibration track on the CD and a sound level meter (Larson-Davis 824).

## Speech Recognition Test Stimuli

According to previous investigations, the PINT (Schafer et al., in press; Schafer & Thibodeau, 2006) is a sensitive, valid, and reliable tool for estimating a child's speech in-noise threshold at the 50% correct level. The current version of the PINT consists of 12 simple, equally-intelligible phrases, spoken by a female speaker, in the presence of four-classroom noise that ascends and descends in intensity during testing (Schafer et al., in press). The Flesch-Kincaid Grade Level of the PINT stimuli was measured as 0.0 (Kincaid, Fishburne, Rogers, and Chissom, 1975), which suggests the lowest vocabulary level measurable on this test. In addition, the appropriateness of the stimuli was verified in three previous studies involving young children who successfully completed the PINT in quiet and in noise (Schafer, 2005; Schafer et al., in press; Schafer & Thibodeau, 2006).

The PINT is similar to the BKB-SIN Test (Etymotic Research, 2005) where a range of SNRs are pre-recorded on a CD. However, unlike the BKB-SIN, children are familiarized with the phrases prior to testing. Also, during testing, children are asked to act out the phrases with a doll and several associated objects in order to avoid examiner scoring issues associated with the child's speech intelligibility (potential articulation errors).

There were a total of 12 PINT lists included on the CD. Each list consisted of 24 pseudo-randomized phrases with each of the 12 phrases occurring twice. As shown in Figure 2, a PINT list consists of phrases presented at approximately 60 dBA (actual intensity of each phrase resulted in equal intelligibility for the normal-hearing adult participants) in the presence of four-classroom noise that decreases by 3 dB for 12 consecutive steps and increases by 3 dB for 12 consecutive steps. The wide range of SNRs was chosen to facilitate testing in children with varying degrees of hearing loss and for testing with FM systems where many children are able to achieve 50% correct performance on the PINT at negative SNRs (Schafer, 2010; Schafer & Thibodeau, 2006).

**Phrases in Noise Test (PINT)**
**LIST ONE - SPEECH 0° / NOISE 180°**

Condition:

| Trial | SNR | Phrase | Response | Trial | SNR | Phrase | Response |
|---|---|---|---|---|---|---|---|
| 1. | +15 | Blow his nose | + | 13. | -18 | Stomp his feet | – |
| 2. | +12 | Brush his teeth | + | 14. | -15 | Blow his nose | – |
| 3. | +9 | Touch his tongue | + | 15. | -12 | Hide his face | – |
| 4. | +6 | Pull his toes | + | 16. | -9 | Pat his leg | – |
| 5. | +3 | Find his shoe | + | 17. | -6 | Find his shoe | – |
| 6. | 0 | Hide his face | – | 18. | -3 | Move his arm | + |
| 7. | -3 | Hold his hand | – | 19. | 0 | Touch his tongue | – |
| 8. | -6 | Move his arm | – | 20. | +3 | Pull his toes | – |
| 9. | -9 | Pat his leg | – | 21. | +6 | Wipe his mouth | + |
| 10. | -12 | Wipe his mouth | – | 22. | +9 | Hold his hand | + |
| 11. | -15 | Stomp his feet | – | 23. | +12 | Brush his teeth | + |
| 12. | -18 | Comb his hair | – | 24. | +15 | Comb his hair | + |

Average = + 3

**Figure 2**. Sample PINT scoring form.

The 12 PINT lists on the CD included six, single-channel tracks for conditions with speech and noise from the same loudspeaker located directly in front of the child (S0/N0) as well as six, two-channel tracks for conditions with speech and noise from separate loudspeakers located at 0 and 180 degrees azimuth (S0/N180), respectively. The S0/N180 condition represents a testing arrangement that may be used by educational audiologists in real classrooms, simulates preferential seating in a small classroom, and may be used for aided testing with unilateral or bilateral hearing aids, CIs, and FM systems. The S0/N180 condition is also preferred because the more common S0/N90 condition would require two conditions with spatial separation with noise speakers toward the right and left sides of the listener. A practice PINT list in quiet and a calibration track were also included on the CD, which consisted of white noise filtered to match the long-term-average spectrum and average root-mean-square intensity of the phrases. Scoring for the PINT was determined in previous investigations (Schafer et al., in press; Schafer & Thibodeau, 2006). To summarize the scoring, on the left-side of the scoring form (Figure 2), the examiner circles the last correct response that is followed by two consecutive incorrect responses, and on the right side, the examiner circles the first correct response that is followed by two consecutive correct responses. The two SNRs associated with the circled responses are averaged to obtain the estimated threshold in noise in dB SNR on a list.

### Teacher Questionnaire

The Preschool Screening Instrument for Targeting Educational Risk (Preschool S.I.F.T.E.R.; Anderson & Matkin, 1996) was completed by some of the children's primary teachers to identify any children who were at-risk for potential educational difficulties and to compare these levels of risk to the children's speech recognition in noise performance. The Preschool S.I.F.T.E.R. consists of primary ratings for expressive communication and socially-appropriate behavior as well as five content areas including pre-academics, attention, communication, class participation, and social behavior. Scale scores for the two primary areas and the five content areas were examined for each child.

### Procedure

Once informed consent was obtained from the child's parent, the examiner read each phrase aloud while simultaneously showing the participant how to act the phrase with a stuffed animal and several objects (Table 2). After familiarization, the child was required to get 100% correct accuracy using the CD practice list in quiet to continue with the test protocol. Each participant completed four randomized test conditions: two S0/N0 PINT lists and two S0/N180 PINT lists. To receive a correct response, the child had to act out the entire phrase. During testing, the parent was asked to complete a case history form. Parents were asked to take a Preschool S.I.F.T.E.R., instructions, and an envelope with pre-paid postage to the child's primary teacher if the child was enrolled in a preschool or elementary school.

## Results

### Speech Recognition in Noise Performance

Average speech-in-noise thresholds of the children with bilateral CIs, bilateral hearing aids, and bimodal stimulation in the S0/N0 and S0/N180 testing conditions are shown in Figure 3 along with data from children with normal hearing in the Schafer et al. (in press) study, which will be further examined in the discussion section. Within-group comparisons using a one-way repeated measures analysis of variance (ANOVA) revealed significant benefit from spatial separation of the speech and noise sources for the group with bilateral CIs ($F$ [1,25] = 8.0, $p$ =.02), bilateral hearing aids ($F$ [1,19] = 10.4, $p$ =.01), and bimodal stimulation ($F$ [1,11] = 19.4, $p$ =.007). These results suggest that all three groups achieved significant SRM on the order of 3.4 dB (SD=4.3) for the bilateral CI group, 5.3 dB (SD=5.2) for the bilateral hearing aid group, and 4.6 dB (SD=2.6) for the bimodal stimulation group. Statistical comparisons among the groups were not appropriate because of the relatively small and unequal sample sizes and because the groups were not purposefully matched for chronological age, listening age, or any other specific characteristics (e.g., hearing thresholds, duration of use, etc.).

**Table 2.** PINT Phrases and Related Objects Used During Test Conditions

| Phrases | Related Objects |
|---|---|
| Move his arm | -- |
| Hide his face | Hand, napkin, or tissue |
| Stomp his feet | -- |
| Comb his hair | Comb or brush |
| Hold his hand | -- |
| Pat his leg | -- |
| Wipe his mouth | Napkin or tissue |
| Blow his nose | Tissue or napkin |
| Brush his teeth | Toothbrush |
| Pull his toes | -- |
| Touch his tongue | -- |
| Find his shoe | Shoe |

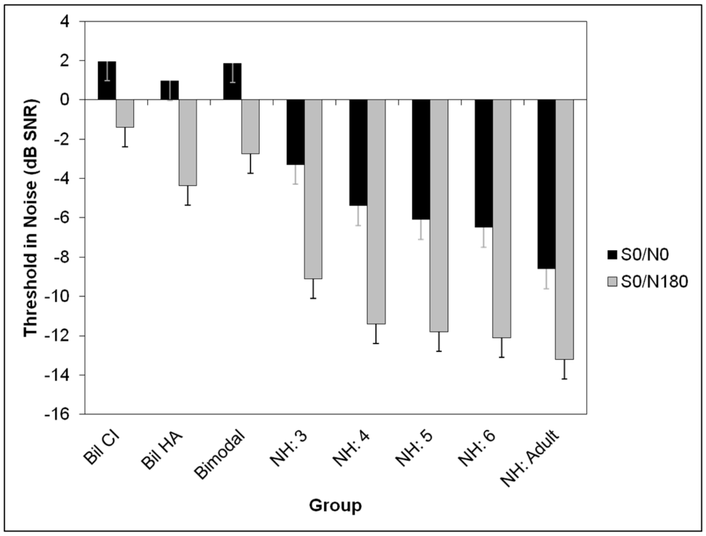


**Figure 3**. Average speech-in-noise thresholds in dB signal-to-noise ratio (SNR) of participants hearing aids (HA) and cochlear implants (CI) as well as those with with normal-hearing (NH) sensitivity obtained using the Phrases in Noise Test (PINT) in conditions with spatially coincident (S0/N0) and spatially seperated (S0/N180) sound sources. *Note*. Normal hearing data from Schafer et al. (in press); Bil=bilateral.

## Teacher Questionnaire

Twenty one teachers chose to return completed Preschool S.I.F.T.E.R. questionnaires, and the average results for the three separate groups are provided in Table 3. When comparing the average ratings for the bilateral CI group in Table 3 to the normal range of Preschool S.I.F.T.E.R. ratings on the left side of the table, most children had no at-risk ratings, with the exception of an average at-risk-teacher rating for the content area of communication. When examining the individual data from each participant in the bilateral CI group, only the communication content area resulted in at-risk ratings from at least half (67%) of the teachers.

The children with bilateral hearing aids showed a different pattern of average ratings (Table 3) as compared to those using bilateral CIs. The average teacher results revealed at-risk ratings for the areas of attention and communication. Examination of the individual ratings for each participant with bilateral hearing aids showed that at least half teachers reported at-risk ratings for the categories of socially-appropriate behavior and attention. On average, the children using bimodal stimulation showed at-risk ratings for socially-appropriate behavior (2 of 4 teachers), attention (2 of 4), and communication (3 of 4).

## Relationships Between Questionnaire Ratings and Speech Recognition

To examine the strength of the relationship between levels of educational risk and speech recognition performance in noise, planned Pearson product-moment correlation coefficients were computed between ratings on the Preschool S.I.F.T.E.R. and speech-in-noise thresholds in each condition for the bilateral CI and the bilateral hearing aid groups. Correlation coefficients were not calculated for the bimodal stimulation group given the small sample size (n=4). The results of these analyses are shown in Tables 4 and 5, and the significance of relationships was determined with a paired *t*-test.

Several medium ($> r = \pm .3$) and strong correlation coefficients ($> r = \pm .5$) were found and represent significant relationships ($p < .05$). For the bilateral CI group, the correlation coefficients between the Preschool S.I.F.T.E.R. ratings and speech recognition in noise yielded medium to strong, significant correlation coefficients between speech recognition in the S0/N0 conditions (Table 4) for expressive communication ($r$ = -.55), academics ($r$ = -.61), attention ($r$ = -.75), communication ($r$ = -.46), class participation ($r$ = -.67), and social behavior ($r$ = -.33). Note that all correlation

**Table 3**. Average Ratings on Teacher Preschool S.I.F.T.E.R.

| | S.I.F.T.E.R. Rating (normal range) | Bilateral CIs (SD) n=9 | Bilateral HAs (SD) n=8 | Bimodal (SD) n=4 |
|---|---|---|---|---|
| Primary Areas | Expressive Comm (14-30) | 16.6 (7.5) | 15.3 (2.4) | 19.3 (4.0) |
| | Soc-App Behavior (12-20) | 13.8 (3.7) | 12.1 (6.7) | 11.5 (3.0) |
| Content Areas | Preacademics (7-15) | 9.9 (2.6) | 9.0 (2.5) | 9.0 (0.8) |
| | Attention (9-15) | 9.8 (3.4) | 7.4 (3.2) | 8.0 (1.8) |
| | Comm (9-15) | 7.9 (4.8) | 8.4 (2.5) | 8.5 (3.0) |
| | Class Participation (7-15) | 10.1 (2.2) | 9.5 (2.1) | 11.5 (2.5) |
| | Social Behavior (9-15) | 10.6 (2.5) | 9.6 (3.1) | 9.3 (3.3) |

Note. CIs=cochlear implants; Comm=communication; HAs=hearing aids; S.I.F.T.E.R.=Preschool Screening Instrument for Targeting Educational Risk; SD=Standard deviations; Soc-App=socially appropriate.

Table 4. Average Ratings on Parent and Teacher Preschool S.I.F.T.E.R. for the Bilateral Hearing Aid Group

| | S.I.F.T.E.R. Rating (normal range) | Parent Ratings (SD) n=9 | Teacher Ratings (SD) n=8 | Correlation Coefficient |
|---|---|---|---|---|
| Primary Areas | Expressive Comm (14-30) | 14.9 (5.1) | 15.3 (2.4) | .55 |
| | Soc-App Behavior (12-20) | 11.1 (5.3) | 12.1 (6.7) | .87 |
| Content Areas | Preacademics (7-15) | 9.7 (2.1) | 9.0 (2.5) | .60 |
| | Attention (9-15) | 7.0 (2.1) | 7.4 (3.2) | .50 |
| | Comm (9-15) | 7.4 (3.4) | 8.4 (2.5) | .65 |
| | Class Participation (7-15) | 8.2 (3.0) | 9.5 (2.1) | .59 |
| | Social Behavior (9-15) | 8.3 (2.3) | 9.6 (3.1) | .81 |

Note. S.I.F.T.E.R.=Preschool Screening Instrument for Targeting Educational Risk; SD=Standard deviations; Comm=communication; Soc-App=socially appropriate. Correlation coefficients were calculated with Pearson's.

coefficients suggest that better teacher ratings in these areas were related to better speech recognition in noise performance. In the bilateral hearing aid group correlation coefficients (Tables 4 and 5) between teacher ratings and speech recognition in the S0/N0 or S0/N180 condition suggest significant, medium relationships for attention (S0/N180, $r = -.40$), class participation (S0/N0, $r = -.34$), and social behavior (S0/N180, $r = -.37$).

## Discussion

### Can the PINT Help to Determine Educational Need?

The primary goal in developing the PINT was to create a tool that was valid, reliable, and sensitive enough to identify young children with hearing loss who may be at risk for listening, learning, and educational problems (i.e., educational need) in the classroom due to poorer-than-normal speech recognition performance. A sensitive speech recognition measure has a clear purpose, identified populations for which test may be used, high validity and reliability, and defined procedures for administration, scoring, and interpretation (Elkins, 1984; Mendel & Danhauer, 1997; Schafer, 2010). Factors relating to the sensitivity of the PINT have been addressed in previous investigations (Schafer, 2010, Schafer et al., in press; Schafer & Thibodeau, 2006). However, the results of the present study provide evidence to support the sensitivity as well as the efficacy and effectiveness of using the PINT for determining educational need in three different ways: (1) the significant differences detected between listening conditions in this study, (2) the significant correlations between PINT results in this study and Preschool S.I.F.T.E.R. ratings, and (3) the comparison of data in this study to previous data from children with normal-hearing sensitivity (Schafer et al., in press), which is provided in a paragraph below.

First, the sensitivity and efficacy of the PINT for determining educational need was shown through the average results within each separate group, which revealed significantly better performance in the listening condition with spatial separation of the speech and noise sources (S0/N180) over the condition with spatially coincident stimuli (S0/N0). In other words, this test was sensitive for detecting significant differences in conditions that, according to a previous study in normal-hearing children (Schafer et al., in press), are expected to produce different results. The average speech-in-noise thresholds in each condition, shown in Figure 3, may appear particularly low (i.e., good) for children with hearing loss. However, this test is essentially closed set following the familiarization procedure, and children are likely to identify a whole phrase by only hearing one word of the phrase. In addition, as discussed in a paragraph below and shown in Figure 3, these thresholds are substantially worse than what was measured in children with normal-hearing sensitivity.

This significant difference between the S0/N0 and S0/N180 conditions suggests the presence of SRM for children with bilateral CIs, bilateral hearing aids, and bimodal stimulation, and all three groups achieved similar amounts of SRM. The average data among groups was not statistically compared because of the expected group differences and varying sample sizes. In comparison to previous studies that reported variable SRM in children using bilateral CIs, bimodal stimulation, or hearing aids (Ching et al., 2010; Litovsky et al., 2006; Van Deun et al., 2010), all three groups in the present study achieved SRM ranging from an average of 3.4 dB to 5.3 dB. This finding is similar to the 3 dB SRM achieved by the children using bilateral CIs in the Van Deun et al. (2010) study. The larger SRMs obtained in the present study may be partially related to greater separation of the noise source (from 0 to 180 degrees) relative to the location of the noise in previous studies (from 0 to ± 90 degrees).

Second, the effectiveness of the PINT for determining educational need was supported with the significant correlations that were computed between the PINT thresholds and the teacher Preschool S.I.F.T.E.R. ratings. For the children with bilateral CIs, performance in the S0/N0 correlated significantly with most areas on the teacher

Table 5. Average Ratings on Parent and Teacher Preschool S.I.F.T.E.R. for the Bimodal Stimulation Group

| | S.I.F.T.E.R. Rating (normal range) | Parent Ratings (SD) n=6 | Teacher Ratings (SD) n=4 | Correlation Coefficient |
|---|---|---|---|---|
| Primary Areas | Expressive Comm (14-30) | 20.5 (6.7) | 19.3 (4.0) | .39 |
| | Soc-App Behavior (12-20) | 13.8 (4.2) | 11.5 (3.0) | .62 |
| Content Areas | Preacademics (7-15) | 10.8 (2.2) | 9.0 (0.8) | -.43 |
| | Attention (9-15) | 10.0 (3.3) | 8.0 (1.8) | .48 |
| | Comm (9-15) | 10.2 (3.4) | 8.5 (3.0) | .47 |
| | Class Participation (7-15) | 11.2 (3.3) | 11.5 (2.5) | .08 |
| | Social Behavior (9-15) | 10.2 (3.4) | 9.3 (3.3) | .49 |

Note. S.I.F.T.E.R.=Preschool Screening Instrument for Targeting Educational Risk; SD=Standard deviations; Comm=communication; Soc-App=socially appropriate. Correlation coefficients were calculated with Pearson's.

questionnaire, which suggests that communication, academics, class participation, and social behavior may be related to the child's ability to recognize auditory stimuli in the presence of background noise. The correlations for the bilateral hearing aid group yielded slightly different results. First, no medium or strong correlations were detected between PINT thresholds and the Preschool S.I.F.T.E.R. in the areas involving academics or communication. Instead, the PINT thresholds for the group with bilateral hearing aids significantly correlated with the areas of attention, class participation, and social behavior. The differences between groups may represent the better unaided hearing thresholds for the bilateral hearing aid group relative to the bilateral CI group. Although not reported, it is highly likely that children in the bilateral CI group had unaided hearing thresholds in the severe-to-profound range while children in the bilateral hearing aid group had a wide range of unaided hearing loss configurations (e.g., mild-to-severe; moderate; moderate-to-severe). In addition, although the CI is expected to provide thresholds in normal-to-mild hearing loss range, the fidelity (e.g., spectral information, fine temporal structure, etc.) of the signal from the CI is limited when compared to what is provided through traditional hearing instruments and acoustic hearing. Overall, the most relevant finding for these analyses was the multiple significant relationships detected between PINT performance and Preschool S.I.F.T.E.R. primary and content areas, which provides empirical evidence that performance in the classroom may be related to the child's ability to recognize speech from the primary talker or teacher.

Finally, the sensitivity of the PINT for determining educational need may be shown by comparing the results in the present study to the average normative data in Figure 3 from young children with normal-hearing sensitivity in a previous investigation (Schafer et al., in press). In Figure 3, when comparing the data from the present study to the previous study, it is evident that the children with hearing loss had substantially poorer average thresholds regardless of the binaural device configuration. To examine whether or not these substantial differences were significant, each subject's PINT threshold in the S0/N0 and S0/N180 condition and SRM was compared to the 95% confidence interval from the normal-hearing children in the previous study with the same chronological age and listening age (i.e., age at testing minus age at CI or hearing aid fitting). According to these comparisons, 93% of children (27 of 29) in the present study (all but two with bilateral hearing aids in the S0/N180 condition) had significantly ($p < .05$) poorer PINT thresholds in the S0/N0 and S0/N180 conditions as compared to the normal-hearing children with the same chronological age. Even when accounting for the child's listening age, which represents the age at the hearing aid fitting or the receipt of the CI, the majority of subjects were outside the normal range for the S0/N0 condition (28 of 29 subjects) and S0/N180 condition (26 of 29 subjects). These comparisons yield noteworthy results because they provide strong evidence that these children do not obtain speech recognition performance in noise that is similar to normal-hearing peers.

The comparisons of SRM between studies yielded different results across the groups. Two of 13 children with bilateral CIs showed higher-than-normal SRM for chronological and listening age, six of ten children with bilateral hearing aids had normal (n=4) or higher-than-normal SRM for chronological and listening age, and two of six children with bimodal stimulation displayed higher-than-normal SRM for chronological and listening age. When examining the cause of the higher SRM in these children, it appears that half of them had poorer S0/N0 performance than other children within their group while the other half had surprisingly good S0/N180 performance relative to the other subjects, which led to a larger discrepancy between the two conditions and the higher SRM. Differences in SRM may be attributed to the longer duration of hearing aid use in the bilateral CI or bimodal groups as well as the degree of hearing loss in the children's non-implant ears.

Overall, the comparisons between studies support sensitivity of the PINT for detecting the expected and significant differences between children with hearing loss and those with normal-hearing sensitivity. In addition, it is interesting to note that despite spatial separation of speech and noise sources in the S0/N180 condition, children with CIs and hearing aids do not perform within normal limits as compared to age-matched peers. Therefore, preferential seating alone, or spatial separation of speech and noise sources, cannot address the deleterious effects of noise on the speech recognition ability of children with hearing loss. In order to achieve performance similar to normal-hearing peers, these children will likely require personal FM systems to consistently improve the SNR as well as classroom accommodations, such as note takers, printed announcements and instructions, captioned movies, and the use of teacher strategies to control noise levels (e.g., noise thermometer poster placed on classroom wall where teacher can indicate to the class with a gesture or stick-on symbol when the noise level is too high).

**Use of PINT in Real Classroom Settings**

The feasibility and appropriateness of using the PINT in a real classroom setting was confirmed in a previous investigation involving 68 children with normal hearing sensitivity (Schafer et al., in press) and is further supported with the results from 29 young children with CIs and/or hearing aids in the present study. Although the children in the current study were tested in several different rooms, the varying acoustics did not appear to influence results because a significant SRM was measured in all three groups. In fact, as previously mentioned, 10 children had higher-than-expected SRM as compared to normal-hearing peers. As a result, the PINT may be used in a small room, as done in this study, or in the child's classroom. Testing in the child's actual classroom would represent performance in his or her customary environment, which is more realistic and also is required according to the Individuals with Disabilities Education Act (2004) during a functional evaluation for assistive technology.

Regardless of the type of room, educational audiologists will need to consider three aspects for testing in a classroom: equipment, classroom acoustics, and interpretation. First, in the current and previous study (Schafer et al., in press), children completed two test conditions, S0/N0 and S0/N180, in classroom settings with the following equipment: a stereo with detachable loudspeakers, a CD player, and a sound level meter. However, the equipment used to present the PINT may be modified slightly for use by educational audiologists in real classroom settings. Our laboratory recently adopted a less cumbersome approach to presenting PINT stimuli through the use of a laptop computer with a CD drive, high-quality computer speakers (e.g., Bose Companion 2, Series II Multimedia Speaker System), and an audio extension cable to allow for a distance of 6 feet between the speakers. The stimuli may be calibrated with a simple sound level meter (e.g., Radio Shack Digital Display Sound Level Meter) or with software on a smartphone (e.g., dB Volume Meter for iPhone).

The second consideration to using the PINT is the acoustics of the classroom where the testing will be conducted. For the most part, the rooms used in the present and previous studies were ideal environments that met the acoustic guidelines set forth by ASHA (2005) and ANSI (2010). As stated in the introduction, however, typical classrooms rarely meet ASHA and ANSI recommendations for acoustics (Knecht et al., 2002). As a result, when using the PINT in a typical classroom, poorer-than-normal performance may be related partially to the acoustics as well as the child's hearing loss, which are both important factors to consider during an evaluation for educational need for an FM system. Rooms with excessive noise or a room with longer reverberation times would negatively influence performance. According to previous research (Neuman et al., 2010), performance only decreased by approximately 1 dB with reverberation increasing from 0.3 to 0.6 seconds, with an additional 1 dB change from 0.6 to 0.8 seconds. It is important to note, however, that when compared to children with normal hearing, those with hearing loss have significantly poorer speech recognition to begin with and are more affected by increased reverberation time, with changes of approximately 1 to 2 dB from 0.3 to 0.6 seconds and 0.6 to 0.8 seconds (Neuman et al., 2010). Therefore, in larger, typical-sized mainstreamed classrooms with reverberation times ranging from 0.5 to 1.0 seconds (Knecht et al., 2002), the audiologist might expect performance to worsen in children with hearing loss by 2 to 3 dB SNR on the PINT relative to performance that would be measured in a smaller room like the one used in this study.

Finally, if used in a child's real classroom, the educational audiologist will need to be able to interpret the PINT scores to determine the presence of educational need relative to normal-hearing peers. When considering a child's individual PINT threshold in dB SNR, this performance represents the SNR where the child will act out 50% of the closed-set phrases correctly. In a real listening situation in a classroom, audiologists strive to provide children with hearing loss approximately 100% correct speech recognition in noise. Therefore, assuming a linear relationship between performance and SNR, as shown in previous investigations (Jerger & Jerger, 1982; Plomp & Mimpen, 1979), the child's dB SNR will need to be at least doubled to predict the SNR where the child could achieve approximately 100% correct on an essentially closed-set task in a classroom. For example, if a child requires a +2 dB SNR to obtain 50% correct performance, he would need at least a +4 dB SNR to hear most of what the teacher says. However, this estimate does not take into account other aspects involved in speech recognition in noise including (1) reverberation, (2) language comprehension, (3) working memory, (4) attention, and (5) effects of closed- vs. open-set tasks. Of course, most classroom instruction and activities involve open-set vocabulary and tasks. No previous data was found that examined the difference between closed-set versus open-set speech recognition performance in children; however, we estimate that open-set tasks will require a better SNR. When using the example discussed earlier in this paragraph, and then adding an additional 1 dB to account for each of the five other child-related factors, the investigators hypothesize that this child would require at least a +9 dB SNR to hear most of the information from the teacher in a classroom environment.

Perhaps a simpler interpretation of a PINT threshold is to calculate the difference score from the average performance of children in the normal hearing study (Schafer et al., in press). For example, Participant 14, who was 6;2 years and used bilateral hearing aids, had a PINT threshold of +3 dB SNR in the S0/N0 condition and -5.25 dB SNR in the S0/N180 condition. Children from the previous study, who were 6-years old and had normal-hearing sensitivity, had an average performance of -6.5 dB SNR (95% confidence interval = 0.7 dB) in the S0/N0 condition and -12.1 dB SNR (95% confidence interval = 2.0 dB). As a result, Participant 14 had deficits of 9.5 dB SNR in the S0/N0 condition and 6.9 dB SNR relative to normal-hearing peers, which represents significantly poorer performance in both conditions. If these results were obtained by an educational audiologist in a real classroom setting, they would certainly warrant a referral to special education for a HAT evaluation. This information about interpreting PINT performance must be carefully explained to parents, teachers, administrators, and other school personnel.

To provide a comparison to children with normal-hearing sensitivity, the 95% confidence intervals for PINT thresholds in 3-, 4-, 5-, and 6-year old children with normal-hearing sensitivity are provided in a previous investigation (Schafer et al., in press). In addition, the audiologist will be able to compare a child's performance to the performance of children with CIs and hearing aids in this study to determine if it is similar.

**Study Limitations**

Limitations in this study are related to (1) the multiple rooms where children were tested, (2) the various devices used by the children, and (3) the characteristics of the PINT stimuli. First, as explained in the methods section, multiple rooms were utilized for testing to increase the sample size in each group. Given the similar acoustics of the rooms in this study, it is highly unlikely that the use of different rooms influenced PINT performance significantly. Varying unoccupied noise levels across the rooms would not have affected performance because the testing was conducted in background noise, and the calibration procedures used for the PINT accounted for the existing unoccupied noise sources. In addition, reverberation times were not of concern because all rooms had reverberation times of less than 0.4 seconds. Previous investigations on the effects of reverberation times on young children's speech recognition performance suggest minimal changes (i.e., 1 dB) in performance in rooms ranging from 0.3 to 0.6 seconds (Neuman et al., 2010). The PINT uses a 3-dB step size; therefore, a change in performance by 1 dB, caused by an increase or decrease in reverberation time, would not result in a different dB SNR obtained on the PINT scoring form.

Second, children in each group were using different CIs and hearing aids; therefore, the use of various devices may have contributed to the variability within the three groups of children. The children with hearing aids may have been using different hearing aid prescriptive strategies, directional microphones, noise reduction technology, compression characteristics, and frequency-compression technology. The children using CIs from different manufacturers were definitely using different sound processing strategies, which determine how speech is coded in quiet and in noisy environments. In addition, the examiners had no way to determine the appropriateness of the fit of the CI or hearing aid. On the other hand, the data presented in this study represent realistic groups of children who are served at various hearing centers and are using bilateral CIs, bilateral hearing aids, and bimodal stimulation. Therefore, these results may be more generalizable to the population of children in the schools with these devices than groups of children selected based on specific device characteristics.

Third, the PINT stimuli cannot directly simulate the complex vocabulary level used in a classroom, the varying intensity of the teacher's voice, or the ever changing background noise level in a typical classroom. Because the PINT is an essentially closed-set task, some children likely identified a phrase correctly by only hearing one word. However, to produce a sensitive and reliable speech-in-noise test, the vocabulary was constrained, the intensities of the speech and noise were carefully controlled, and stimuli were adjusted (Schafer et al., in press). Despite the fact that the PINT may not directly predict speech recognition during classroom instruction, it does appear to predict classroom performance given the correlations in the present study between teacher ratings on the Preschool S.I.F.T.E.R. and PINT performance.

Finally, the results of the planned correlation analyses were somewhat limited due to the incomplete return rate for the teacher questionnaires (i.e., small sample size) and the within-group variability associated with ages, devices used by the children, and other child-related factors (e.g., duration of device use). When multiple correlations are calculated with small sample sizes, interpretation of correlation coefficients may be misleading due to the colinearity between the variables. Because of these limitations, the researchers only considered medium and strong correlation coefficients worthy of reporting in the text of the results section despite the fact that almost all relationships were significant according to *t*-tests (Tables 4 and 5).

**Study Summary**

According to the results in this investigation, the PINT is a feasible, sensitive, efficacious tool for assessing speech-in-noise thresholds in young children with CIs and hearing aids, and the PINT may be used to identify children who are at risk for listening difficulties and educational problems in the classroom. Pairing the PINT with a Preschool S.I.F.T.E.R. completed by the teacher may provide even more evidence regarding the child's level of functioning in the classroom. The three groups of children in this study, including those using bilateral CIs, bilateral hearing aids, and bimodal stimulation, showed better speech recognition performance in noise in the listening condition with spatial separation of speech and noise sources as compared to a condition with speech and noise from the same location. These results suggest that, on average, children with these binaural listening arrangements are able to achieve significant SRM.

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