The basic goal of amplification is to provide audibility for speech without making sounds uncomfortably loud. These requirements must be followed with special care with pediatric patients to ensure they have the opportunity to develop their speech, language, and auditory skills to their full potential. This is because young children have more difficulty filling in missing information than do older individuals whose hearing loss occurred after they had acquired language.

Before discussing the fitting of non-linear instruments on a child, let’s examine how a linear hearing aid meets the basic amplification goals. The hearing aid gain is set so that conversational speech is audible and the maximum output is set below the wearer’s discomfort level. When the listeners are trying to hear soft speech (e.g., a whisper), they are instructed to turn up the volume control (VC). When listening to loud or shouted speech, they are instructed to turn down the VC.

Unfortunately, until children are old enough to understand the proper use of the VC, they will be unable to make the appropriate volume adjustments to their hearing aids. This is one practical reason why all young children should be fitted with non-linear hearing aids.

A non-linear hearing aid adjusts its gain based on the input level. In single-channel, non-linear instruments, the loudest input signal controls the overall gain of the hearing aid. For example, in a room where an air conditioner generates loud, low-frequency noise, the single-channel processor will turn down the gain across all frequencies. This, of course, reduces the audibility of all inputs, including high-frequency speech sounds.

To allow for independent gain control in separate frequency regions, the hearing aid must have multiple channels. In the case of the air conditioner, a three-channel, non-linear hearing aid would reduce gain in the low-frequency channel without changing the gain in the mid- and high-frequency channels. This processing may allow more gain for soft inputs such as high-frequency speech sounds (e.g., /s/ and /h/).

Another consideration with hearing aids is ensuring the audibility of soft sounds. One approach is to lower the compression threshold of the non-linear hearing aid. When this is done, only the gain for the low-input sounds is increased, while gain for conversational and loud speech remains as prescribed for the hearing loss.1

Frequently, soft speech and soft conversational speech sounds are as low as 20 dB HL.2 To make these sounds audible, maximum gain should be provided for soft sounds so as to produce aided thresholds in the vicinity of 20 dB HL. Therefore, a desirable compression threshold would be close to 20 dB HL. Such a threshold allows high gain for soft sounds in order to ensure the audibility of soft inputs but does not compromise performance at higher input levels.

While non-linear hearing aids seem like a logical choice for pediatric patients, their use has not been widespread. A survey published in 2001 reported that more than 50% of hearing aids dispensed to children were linear.3 There are at least two possible explanations for these findings. One is the relative novelty of fitting children with non-linear signal processing compared to the long history of giving them linear hearing aids. The other may be that third-party payers frequently require additional documentation before they will reimburse for non-linear hearing aids.

**PEDIATRIC HEARING ASSISTANCE PROGRAM**

Realizing the hurdles to be overcome before non-linear hearing aids can become the standard for children, Widex Hearing Aid Company recently initiated the Pediatric Hearing Assistance Program (PHAP). This program has two goals: (1) to provide appropriate hearing care to children of limited financial means, and (2) to collect information documenting the benefits of non-linear pediatric amplification. Each year, the company donates $100,000 worth of Widex digital hearing aids to five prominent facilities, which fit them on pediatric clients with limited resources. In return, the hearing aid recipients allow the sites to monitor their speech, language, and hearing skills for 3 years. To date, the PHAP has helped 34 children from infancy to 17 years of age get advanced digital hearing aids. This article reports some of the initial findings from this program.
The PHAP protocol was developed to make it possible to document hearing aid outcomes for children across multiple facilities. It was adapted from the standard comprehensive hearing aid services that these facilities were already providing so as to minimize any extra burden on the professionals at these facilities. The protocol does not seek to include every measurement that should be collected from each child, but rather is intended to be a realistic method for obtaining some meaningful longitudinal data across facilities.

Prior to fitting the hearing aids, the audiologist conducts a thorough case history and audiometric evaluation of the child. A speech-language pathologist conducts an evaluation to provide a baseline of the child’s speech and language abilities and to ascertain what speech and language services the child requires. Annual speech-language evaluations document any changes over time.

The Widex hearing aid fitting software, Compass, is used to fit the hearing aids. In situ thresholds are obtained during the hearing aid fitting (i.e., Senso-gram), combined with a test to decrease the risk of feedback.

The hearing aid fitting is verified to ensure that soft sounds are audible and loud sounds are not uncomfortable. Aided sound-field thresholds are obtained to document the softest sounds that the child hears through the instruments. To make sure that meaningful soft sounds are audible, Widex recommends that aided thresholds be in the vicinity of 20 dB HL across most frequencies (with noted exceptions). Noisemakers are used to verify that output is not too loud or uncomfortable.

The protocol employs aided word-recognition scores as a measure of hearing aid benefit for the older children and it uses questionnaires to validate performance. These are designed to provide benefit information about the hearing aid and to determine any need for fine-tuning. The data collected at each site are sent to Widex for analysis.

RESULTS
Because of the open-ended enrollment of pediatric patients in the PHAP, it was anticipated that the data would be relatively heterogeneous. This makes group analyses difficult. To facilitate this discussion, the children have been divided into two age groups.

**Group 1**

Group 1 contains 18 children (9 females, 9 males) between 6 and 17 years of age. In this group, seven patients were fitted with the Senso Diva (three CICs, one ITE, and three BTEs); nine with the Senso Plus (all BTEs); and two with the Senso P-38 super-power BTE.

Figure 1 shows the average unaided and aided sound-field thresholds for 15 of the children in Group 1. The average unaided thresholds for 500, 1000, 2000, and 4000 Hz were 47, 54, 58, and 64 dB HL, respectively. The average aided thresholds for the four frequencies improved to 23, 19, 24, and 30 dB HL, respectively. Three children in Group 1 had not completed unaided sound-field testing at the time of this report; however, their aided thresholds were also in the target range of 20 dB HL.

It is important to remember that the interpretation of the aided sound-field threshold differs between non-linear and linear hearing aids. In a linear hearing aid, it reflects the average gain for a conversational level input. In a non-linear hearing aid, it reflects the gain for a low-level input. These aided thresholds suggest that the children (with moderate-severe hearing losses on the average) can hear soft sounds in the range of 20 dB HL. It may be that the low compression threshold of the hearing aids makes this possible.

We used aided word-recognition scores as an objective measure of hearing aid benefit. We obtained scores for three conditions: speech presented at a soft level (35 dB HL), speech presented at a moderate level (50 dB HL), and speech presented at a moderate level in noise (50 dB HL at +6 dB SNR). For all conditions, W-22 words were presented from the front and noise from the back. The noise was a speech-shaped broadband noise generated from the audiometer. Figure 2 shows the aided word-identification scores for 16 of the children in Group 1 (data for two children were missing).

For six of the children, the scores for both soft and conversational speech exceeded 90% correct. This indicates that, despite the difference in input levels of...
Non-linear hearing aids for children

For the speech-in-noise condition, 11 children had higher than 80% performance. Seven children had nearly the same scores (less than 5% difference) in noise as in the conversational speech-in-quiet condition. Of the 11 children with scores above 80%, eight were fitted with directional hearing aids, three with CIC hearing aids, and one, who has a severe-to-profound loss, wears the omnidirectional Senso P-38 super-power BTE. The directional-microphone system is most likely responsible for the good speech-in-noise performance of most of the children. For the other children, the reasons for the good performance in noise are still under investigation.

Despite the general trend of excellent speech recognition at both soft and moderate input levels, some children had lower scores. These differences may be explained by the individual characteristics of these children. For example, child G is developmentally delayed. Child L is learning English as second language. On the day of the measurements, child O’s earmold needed to be replaced, which limited his available gain.

The Child Home Inventory for Listening Difficulties inventory® focuses on the listening abilities of the child in 15 environments (e.g., at the dinner table, in a car) and is completed by both the child (Figure 3) and the parent/caregiver (Figure 4). Figures 3 and 4 present the overall pre- and post-fitting rating for each individual child. A rating of 8 corresponds to a subjective category of “Great” while a 1 rating corresponds to “huh?” Data are available for 15 of the children (three children in the group have incomplete data). Child identifications are consistent across figures.

A comparison of the CHILD results pre- and post-fitting with the digital hearing aids shows that all children and parents reported decreased listening difficulty after the fitting. Prior to wearing the digital instruments, the children wore or had worn analog hearing aids that typically used linear amplification. For two-thirds of the children, reported listening difficulty improved by at least two categories on the CHILD. Child A, for example, reported “OK but not easy” listening prior to getting hearing aids and “Good” to “Great” listening when aided.

To consider a parent’s responses, look at child G, who is developmentally delayed. The parent reported that the child “Sometimes gets it, sometimes doesn’t” with the prior hearing aids. After the child used the new hearing aid for a month, the parent reported between “OK but not easy” and “Pretty good” listening.

An analysis of the individual questions on the CHILD reveals an interesting finding. The children and their parents/caregivers both reported the greatest improvement on the same item, which dealt with a parent calling the child from another room when the child cannot see the parent. This is often a difficult listening situation because the separation between the parent and the child decreases the amplitude of the parent’s voice level. In this situation, the responses from both the children and parents improved from “Sometimes get it, sometimes don’t” to “Pretty good.” This improvement reflects the improved audibility of soft sounds provided by a multi-channel, non-linear hearing aid with a low compression threshold.

Group 2

The second group was composed of 12 children (4 females, 8 males) from newborn to age 3. There are no 4- and 5-year-old children in the program so these ages were not included in either group. Ten of these children are wearing the Senso Diva BTE, one the Senso Plus BTE, and one the Senso P-38 super-power BTE.

The aided sound-field thresholds for six children in this group are shown in Figure 5 (aided sound-field thresholds are still being acquired for the others). Among these six, the hearing losses are documented as moderate-severe between 500 and 4000 Hz obtained in sound-field or with insert earphones. The average aided thresholds ranged from 21 to 28 dB HL between 500 and 4000 Hz. The aided thresholds of these young children suggest that the softest speech sounds around 20 dB HL are audible.

The infants in this group were fitted from ABR measurements since behavioral thresholds were unavailable. By using the pediatric rationale incorporated into the Compass fitting software, the audiologists could quickly fit the digital hearing aids with the ABR test results.

When children cannot provide feed-
back on the hearing aid fitting, the role of the parent/caregiver becomes more critical in documenting benefit and deciding if fine-tuning is needed. The Widex Pediatric Hearing Aid Questionnaire for Parents was developed to assist parents/caregivers in reporting observations regarding the child’s new hearing aids. Items cover a wide range of developmental levels and include observations in various communication environments (e.g., watching TV, in a car, in a playground). Thus, when interpreting these results, one must bear in mind that some items on the form are inappropriate for some children because of their particular developmental level, not because of any lack of efficacy of the hearing aids. Despite this potential limitation, this form provides insights about children who cannot accurately report their reactions.

Figure 6 displays some average responses appropriate for infants and young children. For example, nine parents reported improved listening behaviors. The parents also reported that the new hearing aids frequently provided responses to soft and moderate level sounds from a distance. The magnitude of improvement compared to the children’s previous amplification (or no amplification) was greater for soft sounds than for moderate-level sounds. This may be attributable to the low compression threshold of the hearing aids.

Since the children in this group are acquiring speech and language skills, it is especially important to scrutinize parental observations in these areas. All parents/caregivers reported changes in their children’s speech-production ability after they were fitted with the digital hearing aids (Figure 6). Figure 6 also displays the number of parents reporting changes in specific listening conditions. Many parents reported improved vocal quality, changes in loudness, production of more speech sounds, and more consistent imitation of speech sounds. These reports are important because they document that these children are continuing to imitate speech sounds and refine their speech productions.

It has been suggested that multi-channel, non-linear hearing aids with low compression thresholds may improve speech production. This processing improves the audibility of speech sounds, especially the consistent audibility of the child’s own voice and may result in more accurate speech production. The preliminary reports of the parents are consistent with the findings of these research studies.

**DISCUSSION**

The data reported here support the use of multi-channel, non-linear hearing aids with low compression thresholds for the pediatric population. On average, the aided sound-field thresholds were about 20-30 dB HL across frequencies. Audibility of inputs at this intensity range suggests the ability to hear soft speech sounds. It is important to recognize that these aided thresholds document audibility of these sounds, not normal hearing sensitivity. The input signals are still processed by a damaged auditory system. But by making the sounds audible, the hearing aids at least enable the child to begin processing the signal.

The aided word-identification scores obtained for soft and moderate speech inputs showed that many of the children performed equally well with both input levels and often had scores of greater than
90% correct. This performance suggests consistent audibility of speech for both soft and conversational speech. As many children, especially very young ones, are unable to use a volume control, the automatic non-linear processing provides the required gain at both inputs.

The CHILD was one tool used with the older children to document subjective benefit in various listening situations. All the children in the older group were either wearing or had previously worn traditional amplification. In all listening situations, the children reported a decrease in listening difficulties with the new aids.

The data reported here are the first results to emerge from the PHAP. We will continue reporting on any significant changes in children enrolled in the program. Our goal is to enable as many children as possible to realize their maximum speech and language potential. Multi-channel, non-linear hearing aids with low compression thresholds may offer the best tool to reach this goal.

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