Conference Keynote Address

Pediatric Amplification: Past, Present and Future

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Introduction

Over the past three and half decades, tremendous gains have been achieved in the speech and hearing sciences. These conceptual and technological advances have improved the lives of children with hearing loss in ways that would have seemed inconceivable three or four decades ago. The goal of this paper is to provide an overview of the field of pediatric amplification in the 1970s, a review of progress over the last 35 years, a summary of the current status, and a discussion of research needs for the future.

In the early 1970s there were no universal newborn hearing screening programs. The average age of identification of children with hearing loss was 3–3 ½ years. Early efforts to improve this situation were a registry to identify newborns who are at high risk for hearing loss and development of the Crib-o-Gram (Simmons and Russ 1974; Simmons, McFarland and Jones 1979). While both procedures improved the early identification of children with severe-to-profound hearing loss, lesser degrees of hearing loss continued to go undetected. Diagnostic procedures to quantify the degree and configuration of hearing loss in infants were limited to behavioral observation audiometry, which is now known to be unreliable and prone to tester bias. Body-worn hearing aids and FM systems were the devices of choice for the pediatric population, but FM systems were used only in academic settings. Most hearing-aid circuits were linear peak clippers, fitting algorithms were based on adult data, and functional gain was used to verify aided performance. At that time, audiologists had limited resources with which to serve the pediatric population and most of the procedures used had not been subjected to scientific scrutiny. Over the next 35 years, the work of researchers from many disciplines gradually expanded our knowledge, resulting in many of the clinical tools that are in use today.

Progress

Early Identification and Quantification of Hearing Loss

In 1993, the National Institutes of Health endorsed the concept of Universal Newborn Hearing Screening (UNHS) in the U.S. Promising results from the Rhode Island Hearing Assessment Project (Maxon, White, Vohr and Behrens 1993) paved the way for the rapid expansion of UNHS programs worldwide. Subsequent studies have shown these programs to be cost effective (Gorga and Neely 2003) and efficacious both in reducing the age at which hearing loss is identified and in improving language outcomes (Yoshinaga-Itano, Sedey, Coulter and Mehl 1998). As a result of the success of UNHS programs, however, clinicians increasingly were faced with the task of fitting amplification to infants within the first few weeks of life. Since reliable behavioral responses to sound cannot be obtained prior to 5–6 months of age in a clinical setting, objective physiological measures were refined to quantify the degree and configuration of hearing loss for this population. Specifically, a variety of methods were developed using auditory brainstem responses (ABR) measures (Don, Eggermont and Brackman 1979; Picton, Ouellette, Hamel and Smith 1979; Gorga, Kaminski, Beauchaine and Jesteadt 1988; Stapells, Gravel and Martin...
1995). More recently, Auditory Steady State Response (ASSR) measures have been explored as an alternative to the ABR. Potential advantages include increased frequency specificity, ease of calibration in dB HL, automatic response detection, and possibly an increased dynamic range. The benefits and limitations of ASSR measures are described in detail in Chapter 3 by David Stapells.

**Signal Processing**

A comprehensive review of advanced signal processing is beyond the scope of this paper. This section will highlight only those achievements that have had a marked impact on the pediatric population. Although slow-acting wide dynamic range compression (WDRC) circuits were commercially available in the early 1970s, fast, dual, and variable time-constant circuits did not emerge until later. Currently, some form of WDRC processing is incorporated in almost all hearing instruments. This type of processing compensates for the reduced dynamic range associated with hearing loss, providing audibility for soft speech and comfort for high-level input signals. Although the signal-to-noise ratio (SNR) advantage with directional microphones appears to be slightly greater for adults than for young children, this technology also has been shown to be beneficial for children as young as four years of age (Gravel, Fausel, Liskow and Chobot 1999) provided that they are sophisticated enough to switch between omni- and directional-microphones modes appropriately.

The development of ear-level FM systems also has had a marked impact on the auditory access of children with hearing loss. Specifically, the ease with which these devices can now be switched between modes (FM only, FM+ hearing instrument, hearing instrument only) has facilitated the use of these systems as assistive devices in difficult listening situations such as the car, noisy store, or the park. Thus, many situations that would have been “lost opportunities” for language stimulation during the day are now accessible to children with hearing loss. Finally, the shift toward digital technology has expanded the signal processing capabilities in hearing instruments to include single-microphone noise reduction, frequency compression/transposition, adaptive directional microphones, and active feedback reduction. In addition, the increased flexibility of digital instruments now allows clinicians an opportunity to fit hearing instruments earlier than in the past because of the ease with which substantial changes in gain, output, and type of processing can be implemented. Marked advances in the area of cochlear implantation have resulted in ear-level devices, improved signal processing, binaural implants, and hearing instrument plus implant combinations.

**Device Efficacy**

Unfortunately, these technological advances have not been accompanied by the methodologies needed to adequately evaluate the efficacy of new devices in young children. For adults with hearing loss, a wide range of subjective and objective methods are available to evaluate the benefit of new technologies. For a variety of reasons, the determination of device efficacy for infants and children is complex and problematic. When introducing a new signal-processing strategy to a child, one would not necessarily expect to see immediate changes in speech production or language skills. For some types of processing, repeated auditory experiences and longitudinal monitoring may be required to observe changes in responsiveness, speech perception, speech production, or language skills. When a longitudinal approach is used to document outcomes, however, it may be difficult to separate the effects of normal development or the influence of other factors (e.g., habilitation, home environment) from the effects of signal processing. Another complication is that the auditory goals of a child with hearing loss can be expected to change over time in a way that generally does not occur for adults. As a result, it may be necessary to develop a series of metrics to reflect changes in performance as a child matures.

Because the evaluation of device efficacy in the pediatric population is complex, it is unlikely that a single outcome measure or a single approach to the problem can provide a means by which to determine efficacy for all types of signal processing. When the effects of acclimatization are likely to be minimal, clinical speech perception measures can be obtained from children as young as three years of age. It is important, however, to design these tests to distinguish the influence of auditory experience, speech and language intervention, educational environment, and phonologic development from the true residual capacity of the damaged cochlea (Boothroyd 1991; Boothroyd, Eran and Hanin 1996; Kosky and Boothroyd 2003). Specifically, if the intent is to assess the efficacy of a particular signal-processing scheme,
a valid test of auditory speech perception should be devoid of lexical, syntactic, and semantic constraints. While nonsense syllables or nonsense words would meet this goal, the use of such stimuli with young children is problematic because it is difficult to provide an appropriate visual reference (e.g., written words, pictures) for each test item. An imitative test format, developed for children as young as three years of age, may hold promise for this purpose (Kosky and Boothroyd 2003).

Another possible option for children as young as four or five years is to use a novel-word learning paradigm to compare two different signal-processing schemes. It is well known that typically-developing children can acquire at least partial meaning of new words with as few as one or two incidental exposures via television or overhearing conversations (Carey 1978; Dollaghan 1985, 1987; Rice and Woodsmall 1988; Rice, Buhr and Nemeth 1990; Oetting, Rice and Swank 1995). It has been suggested that this type of learning facilitates the rapid word acquisition that is observed in early childhood. Although this paradigm has been used extensively to investigate word learning in language-delayed children, only two studies have been reported with hearing-impaired (HI) children (Gilbertson and Kamhi 1995; Stelmachowicz, Pittman, Hoover and Lewis 2004). Both studies found that children with hearing loss performed more poorly than normal-hearing (NH) children on this type of task. The latter study, however, also investigated whether the paradigm might be sensitive to simple manipulations of stimulus characteristics. In the Stelmachowicz et al. study, each child viewed a 4-minute animated slide show containing eight novel words represented by unique pictures. Half of the words were presented at 50 dB SPL and the other half at 60 dB SPL. After hearing the story twice, children were asked to identify each word from a set of four pictures. While significant level effects were observed for both the NH and HI groups, the effect was more pronounced for the children with hearing loss. Mean data for the NH group revealed that 2.4 words were retained at 60 dB SPL, decreasing to 1.1 words at 50 dB SPL (~2-fold difference). Similar data for the HI group showed that 1.5 words were retained at 60 dB SPL but only 0.4 words at 50 dB SPL (~4-fold difference). Thus, level effects were much more detrimental for the HI group, supporting the use of WDRC circuitry. This sensitivity to presentation level also suggests that this type of paradigm may be an effective tool for studying various forms of hearing-aid signal processing schemes in a single test session.

Fitting and Verification

Another area of marked progress is the hearing-aid fitting and verification process. Although it has been known for some time that the SPL developed in a human ear canal is substantially different than that measured in a standard 2cc coupler, the development of clinical probe-microphone systems in the early 1980s raised new concerns regarding the fitting of hearing instruments to children. Specifically, studies revealed that the SPL in the ears of infants could be as much a 15–20 dB higher than in adult ears. Furthermore, adult-like values are not reached until six or seven years of age (Barlow, Auslander, Rines and Stelmachowicz 1988; Feigin, Kopun, Stelmachowicz and Gorga 1989). To facilitate real-ear measures in infants as young as a few weeks of age, an ingenious real-ear-to-coupler difference (RECD) procedure was developed by Seewald and colleagues at the University of Western Ontario (Moodie, Seewald and Sinclair 1994). Subsequent studies have shown good test-retest reliability for RECD measures (Scollie, Seewald, Cornelisse and Jenstad 1998; Tharpe, Sladen, Huta and McKinley 2001). Additional information on the RECD procedure can be found in Chapter 5 by Kevin Munro.

In 1973, Erber described a procedure to display thresholds, amplified speech, and maximum output as a function of frequency in order to easily visualize the “auditory dynamic range”. It was not until the development of clinical probe-microphone systems, however, that this procedure was introduced into clinical practice. Probe-microphone measures provided a unique opportunity to easily quantify the audibility of speech across a range of input levels. As various forms of nonlinear signal processing were developed, the utility of the amplified spectrum became crucial to the hearing-aid fitting process. Amplified spectra are provided in some hearing-instrument fitting algorithms (Seewald et al. 1997; Byrne, Dillon, Ching, Katsch and Keidser 2001) as well as in a program known as the Situational Hearing Aid Response Profile (Stelmachowicz, Kalberer and Lewis 1996). Displays from the latter program are shown in figure 1, where each panel depicts the amplified spectrum and an Aided Audibility Index (AAI) for a different listening condition. These types of displays allow a visual comparison of audibility across different signal-
processing schemes and/or listening conditions. Such information is useful when counseling parents and explaining the consequences of hearing loss to educators (e.g., justifying the use of FM technology).

**Fitting Algorithms**

In the late 1970s and early 1980s when systematic hearing-aid fitting algorithms began to emerge, they were based solely on data from HI adults (McCandless and Lyregaard 1983; Byrne and Dillon 1986; Byrne and Murray 1986). In 1985, Seewald, Ross and Spiro proposed a fitting strategy developed exclusively for preverbal HI children. Their audibility-based approach was designed to consider the effects of listener-talker distance, the role of auditory self-monitoring, ear canal acoustics, and psychoacoustic factors. Numerous investigators have provided a wide range of evidence to support the notion that the acoustic needs of young children are qualitatively different than those of adults. For example, Neuman and Hochberg (1983) investigated the effect of reverberation time on phoneme perception as a function of age. As shown in figure 2, there is a marked effect of age on performance for the two reverberant conditions that continues until the mid teens. Nittrouer and Boothroyd (1990) studied the effect of semantic context on word recognition in noise for adults and 4–6 year-old children (see figure 3). Adult-child differences were relatively small for non-meaningful (low-predictability) sentences. When high-predictability sentences were used, performance increased by 30% for the adults and only by 15% for the children.

In 2000, Stelmachowicz, Hoover, Lewis, Kortekaas and Pittman studied the effects of audibil-

![Figure 1. Amplified spectra for four different listening conditions. Open circles show thresholds, asterisks show the real-ear maximum output, and the cross-hatched regions shows the portion of the amplified speech spectrum that is audible. Each panel also gives an Aided Audibility Index (AAI).](image-url)
ity on the recognition of words in short meaningful sentences. Figure 4 shows word recognition as a function of audibility index for five-year-olds, seven-year-olds, and adults. Mean performance for the adults was 60% at an AI of 0.2. In contrast, performance for the 5- and 7-years olds was 2% and 10%, respectively. Stated differently, to achieve 90% performance the 5-year olds required an AI of 0.8, the 7-year olds required an AI of 0.6, and the adults only required an AI of 0.4.

In 2002, Hall, Grose, Buss and Dev (2002) investigated the effect of masker type on spondee recognition for adults and children. As shown in figure 5, when the masker was speech-shaped noise, adult-child differences were relatively small. When a twotalker masker was used, adult-child differences in performance increased markedly, suggesting that informational masking is greater for children than for adults. Additional studies have shown adults and children differ in how they use acoustic cues in speech perception (Morrongiello, Robson, Best and Clifton 1984; Nittouer and Studdert-Kennedy 1987; Nittouer 1992; 1996) and in listening strategies (Oh, Wightman and Lutfi 2001; Wightman, Callahan, Lutfi, Kistler and Oh 2003).

Taken collectively, the above studies suggest that young children are unable to take full advantage of the many acoustic and linguistic redundancies in speech. In contrast, through years of experience with spoken language, adults have learned to use alternate cues to perception in difficult listening situations. Studies have shown that the influence of auditory experience on speech and language development begins at or even before birth in children with normal hearing. For example, DeCasper and Fifer (1980) showed that newborn infants are able to distinguish their mother’s voice from that of other talkers. By 6–7 months of age, infants are able to recognize the sounds, sound sequences, and rhythmic patterns of their native language (Werker and Tees 1984; Jusczyk and Luce 2002). By 7–10 months, they are able to generalize words and phrases across talkers (Kuhl 1983; Houston and Jusczyk 2000) and for most children, early words emerge by 12 months of age. It is likely that, even with early identification and amplification, the magnitude and quality of early auditory experiences differ between children with normal hearing and those with hearing loss. Specific knowledge regarding the early acoustic needs of HI children may help to provide improved rehabilitative and amplification strategies for this population.

In the late 1990s, two studies concluded that the provision of high-frequency gain may not improve, and in some cases may degrade, speech recognition for listeners with sensorineural hearing loss (Hogan...
Although these studies were conducted only with adults, the general concept that “amplification in the high-frequencies was not necessary or beneficial” was subsequently applied to children in clinical practice. For adults and older children with well-developed language systems, there may be sufficient linguistic knowledge to compensate for a loss of audibility in the high frequencies. When hearing loss is congenital or acquired in early life, however, this same reduction in audibility may be more problematic. To assess potential developmental effects, Kortekaas and Stelmachowicz (2000) investigated the effects of low-pass filtering on the perception of /s/ in NH children (5, 7, and 10 year olds) and adults. The phoneme /s/ was selected because of its linguistic importance in the English language. Specifically, it is the 3rd or 4th most frequently occurring phoneme and denotes important linguistic functions such as plurality, tense, and possession (Rudmin 1983). Results revealed that the children required a wider signal bandwidth than adults to perceive /s/ correctly when stimuli were presented in noise. In a subsequent study, Hall et al. (2002) investigated the spondee recognition threshold as a function of masker type (2-talker, speech noise) for adults and 5–10 year-old children.
study, Stelmachowicz, Pittman, Hoover and Lewis (2001) examined the extent to which high frequencies can provide useful information for fricative perception. Nonsense syllables containing the phonemes /s/, /ʃ/, and /θ/, produced by male, female, and child talkers, were low-pass filtered at 2, 3, 4, 5, 6, and 9 kHz. Results revealed that the performance for both groups of children was significantly poorer than their adult counterparts at similar bandwidths. Likewise, both HI groups performed more poorly than their NH counterparts. Notably, significant talker effects for /s/ were observed. As shown in figure 6, optimum performance for the male talker was reached at a bandwidth of approximately 4–5 kHz whereas optimum performance for the female and child talkers did not occur until a bandwidth of 9 kHz. These findings are consistent with the spectral characteristics of /s/ for male, female, and child talkers (see figure 7).

The close relationship between perception and the acoustic characteristics of /s/ may have important implications for the speech and language development of young children with hearing loss. Even with the most advanced technology, current hearing instruments provide relatively little gain above 5 kHz, particularly in behind-the-ear models. Acoustic feedback also may limit the amount of high-frequency gain that can be achieved when fitting hearing instruments to infants and young children. Thus, in a subsequent study, Stelmachowicz, Pittman, Hoover and Lewis (2002) studied the accuracy with which HI

Figure 6. Low-pass filter frequency (kHz) at which optimum performance was achieved as a function of talker for NH and HI adults and children (from Stelmachowicz et al. 2001; reproduced with permission JASA).

Figure 7. One-third octave band spectra for /s/ spoken by adult male, adult female, and a child (reproduced with permission from Stelmachowicz et al. 2001).
children could detect the inflectional morphemes /s/ and /z/ when listening through hearing instruments. Children were required to identify the singular and plural forms of various nouns spoken by either a male or female talker. Although the performance for a group of five-year old NH children was >90% for both talkers, the HI children showed significant performance differences between the male (87%) and female talkers (79%). A factor analysis revealed a significant relation between performance and aided sensation level in the 2–4 kHz range for the male talker. For the female talker, this range increased to 2–8 kHz. These results are consistent with the acoustic spectra of each talker and suggest a strong relation between the physical acoustics of the stimuli and perception.

Studies with HI children also have shown that the production of /s/ is often abnormal (Elfenbein, Hardin-Jones and Davis, 1994). Cornelisse, Gagné and Seewald (1991) suggested that for self-monitoring purposes, it is important to consider the acoustic characteristics of one’s own speech received at the ear. They found that the long-term average speech spectrum measured at the ear contained 5–6 dB more energy below 1 kHz and 10 dB less energy above 2 kHz than the spectra measured at 0° azimuth. In 2003, Pittman, Stelmachowicz, Lewis and Hoover compared the short-term spectra of various self-produced speech sounds measured at the ear for adult males, adult females and 2- to 4-year old children. Figure 8 shows a comparison across these three groups for the phonemes /s/ and /sh/. While these differences may have little influence on the development of speech production in children with normal hearing, the typical upper cut-off frequency of BTE hearing instruments (4–5 kHz) may compromise the self-monitoring of important high-frequency speech sounds for children with hearing loss.

Further evidence to support this notion comes from a five-year longitudinal research program underway at Boys Town National Research Hospital. In this study, spontaneous speech samples were recorded from a group of 20 NH children and 12 HI children who were identified and aided prior to 12 months of age. The results of a preliminary analysis at 14–16 months of age are shown in figure 9. The y-axis shows the proportion of vowels, stops, nasals, glides, liquids and fricatives relative to that of the 20 NH children.
Results suggest that vowel production is closest to that of the NH group and fricative production is the most delayed. These findings are consistent with our previous concerns about the limited bandwidth of hearing instruments.

Outcome Measures

For adults with hearing loss, speech perception measures in quiet and/or noise typically are used as objective measures of benefit and a wide variety of subjective metrics also are available (see Weinstein 1997, for a review of this literature). Formal tools for the documentation of benefit in young children did not begin to emerge until the 1990s. At present, no clinical tests of speech perception can produce reliable data for children < 3 years of age. As a result, most metrics are subjective in nature. Inventories designed to monitor early development in the home environment in relation to hearing-instrument usage began to emerge in the 1990s (e.g., Anderson and Matkin 1996; Zimmerman-Philips, Osberger and Robbins 1997; Palmer and Mormer 1999; Anderson and Smaldino 2000; Stredler-Brown and Johnson 2003). A detailed review of this literature is beyond the scope of this paper, but a brief discussion of the strengths and limitations of these metrics will be presented.

Strengths and Limitations

In general, most of these metrics are designed to provide an estimate of developmental changes in auditory behavior. This information can provide parents and early interventionists with a way to monitor auditory responsiveness and development over time. The expectations and goals for individual children, however, are likely to vary with both developmental age and degree of hearing loss. As a result, these tools tend to be relatively insensitive. In addition, many of the clinically available tools are not designed to provide an easy comparison with data from normally developing children. While relative improvements in auditory responsiveness over time are informative, a comparison with children with normal hearing may provide important insights into the efficacy of amplification and habilitation. For example, an increased deviation from normal performance as a function of age might signal a need for changes in intervention strategies. Furthermore, systematic studies of the validity and reliability of parental observation have not been conducted. Specifically, the correlation between early subjective data and ultimate speech and language outcomes is not known.

Identify Objective Correlates

As the age of identification of hearing loss decreases, the need for objective measures of performance increases as well. There is a need to identify objective measures that correlate with the perceptual measures that can only be obtained reliably from older children. Recent studies have suggested that it may be possible to use evoked potential techniques to measure differential responses to various acoustic contrasts thus providing an estimate of the auditory capacity for speech perception (Martin and Boothroyd 1999; Martin and Boothroyd 2000; also see Chapter 8 by Suzanne Purdy and colleagues).

Current Status of Children with Hearing Loss

Universal newborn hearing screening, improved electrophysiological techniques, advances in signal processing, and systematic hearing aid fitting procedures have produced a cohort of HI children who have received “optimal” services based on current knowledge. These children provide a unique opportunity for researchers to evaluate the efficacy of current models of early intervention. Unfortunately, for a variety of reasons, some children continue to be diagnosed with hearing loss after the first year of life. A developmental comparison across early-identified, late-identified, and NH children can provide important insights into the efficacy of current amplification and intervention strategies and help identify potential areas where improvement is needed.

Figure 10 compares expressive language data as a function of age for NH and HI children. The four panels show data for children falling in the 25th, 50th, 75th, and 90th percentile of each group. In each panel, the open circles represent normative data from the MacArthur Communicative Development Inventory (Fenson et al. 1993) and the filled circles show data from 202 HI children from a Colorado study by Mayne, Yoshinaga-Itano, Sedey and Carey (2000). In general, the slope of the functions for the HI children is considerably shallower than it is for the NH children, particularly for the lower half of the distribution (25–50th percentiles). By 32–34 months of age, data
for HI children in the 50th, 75th, and 90th percentile ranges begin to parallel the NH data, but their expressive vocabulary is still delayed by 12–16 months relative to the NH children.

Preliminary analyses of data from the early ID group in our BTNRH longitudinal study are consistent with the Mayne et al. data (2000). Specifically, it appears that only the top performers within the HI group are achieving expressive language scores at or above the median (50th percentile) for the NH group, despite early identification and remediation of hearing loss. These results suggest that factors other than early identification and amplification may play a crucial role in the speech and language development of children with hearing loss. Our challenge for the future is to identify the factors responsible for the continued speech and language disparities between NH and HI children.

**Future Research Needs**

Previous studies have shown that socioeconomic status, maternal education, intervention strategies, and family involvement are related to language outcomes. It is also possible that improvements in amplification may increase early auditory access for children with hearing loss. This final section will discuss research needs in relation to this critical clinical issue.

**Do the Amplification Needs of HI Children Change Developmentally?**

As mentioned earlier, we now have hearing-aid selection algorithms as well as clinical fitting procedures that are designed specifically for infants and young children. Is it possible that we need to be more
specific from a developmental standpoint? For example, can early improvements in auditory access lead to better outcomes? In clinical practice, FM systems are rarely recommended as assistive devices for children less than 2–3 years of age. Can earlier use of FM systems in selected environments increase auditory access and facilitate language development? Studies are needed to address this issue as well as the many practical problems associated with FM use in young children (e.g., parent/caregiver training, FM modes, interference).

When can technological advances that are known to be beneficial for adults be used successfully with children? At some point in time, children begin to approach adult-like performance on specific auditory tasks. Unfortunately, the timeline differs depending upon what is actually being measured. For example, children comprehend the syntax of their native language by 5–6 years of age but do not reach adult-like performance when listening in noise until the mid-teenage years. Developmental studies are needed to determine the age at which specific amplification strategies (e.g., multiple-memory devices, frequency compression, single-microphone noise reduction) can be optimally applied to young children with a minimum of practical problems.

What Is the Timeline of Acclimatization to New Technology?

A clear understanding of auditory learning and acclimatization in relation to the hearing-aid fitting process is necessary to determine the need to modify amplification, alter intervention strategies, and/or explore the possibility of subtle learning problems unrelated to hearing loss. To date, the time course of acclimatization to amplification and/or changes in signal processing has not been studied in young HI children. Such studies are much more difficult to conduct with children than with adults. The results will probably depend upon the age of the child, the degree of hearing loss, the home environment, the intervention program, etc. Knowledge of the timeline of acclimatization is critical to many of the clinical decisions that must be made (altering amplification characteristics, selecting an alternate circuit). It is also likely that the time course of acclimatization may differ across technologies or processing schemes. One might expect that more extreme processing schemes (e.g., cochlear implant processing, frequency compression) may require a longer period of acclimatization than amplitude compression or single-microphone noise reduction, but this also has not been confirmed experimentally.

How Should the Success of Amplification Be Monitored?

A variety of outcome measures (e.g., speech perception, judged intelligibility, listening comfort) can be used to assess hearing-aid benefit in adults. Assessing device efficacy and language outcomes for infants and children with hearing loss is much more complex, but such data are needed to determine if and when changes in intervention are warranted. At present, it is not known whether parental observations of early auditory behaviors correlate well with later language outcomes. It is also not clear if other early speech and language milestones (e.g., acquisition of specific speech sounds, morphological development) can be monitored reliably by parents. It may be necessary to develop a systematic training program to assist parents in monitoring auditory development. The acquisition of data on the early auditory development of a large group of HI children ultimately may provide a means by which to predict later success from early learning landmarks.

Conclusions

It is clear that we have come a long way since the early 1970s. Children with hearing loss are being identified at birth and in many cases remediation, including amplification, is implemented prior to six months of age. Despite the impressive progress of the last three decades, there is still much to learn. Factors responsible for speech and language disparities between NH and HI children are still unknown. The need for further exploration of the amplification needs of children, as well as the development of age-appropriate outcome measures continue to challenge researchers and clinicians alike. As knowledge is gained, it can be expected that the performance gap between NH and HI children will continue to close.

References

inventory of listening difficulties (CHILD). Tampa, FL: Educational Audiology Association.


Kortekaas, R. W., and Stelmachowicz, P. G. 2000. Bandwidth effects on children’s perception of the


