Hearing Aid Outcome Measures for Children

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Abstract

The provision of appropriate amplification for a young hearing-impaired child is critical as the aided speech signal will be used for the development of speech and language. The purpose of this paper is to provide an overview of the complex issues surrounding the documentation of hearing aid outcomes in the pediatric population. In the first two sections of the paper, the unique characteristics and needs of the pediatric population and factors complicating the measurement of outcome are described in detail. The third section provides a review of literature on existing outcome measures for children and the fourth section is devoted to a discussion of alternative approaches. The final section is an overview of clinical and research needs in the area of hearing aid outcome measures for children.

Key Words: Children, hearing aid, hearing loss, outcome

Abbreviations: AAI = Aided Audibility Index; ABR = auditory brainstem response; AI = Articulation Index; APHAB = Abbreviated Profile of Hearing Aid Benefit; CL = compression limiting; COSI = Client-Oriented Scale of Improvement; DSL = Desired Sensation Level; HPIC = Hearing Performance Inventory for Children; LDL = loudness discomfort level; LIFE = Listening Instrument for Education; PC = peak clipping; SIFTER = Screening Instrument for Targeting Educational Risk; WDRC = wide dynamic range compression

Numerous approaches are available to evaluate the efficacy of a particular hearing aid fitting for adults. Objective measures of benefit typically have been conducted in a structured clinical or laboratory setting and have focused on speech recognition under a variety of test conditions. It has been suggested that this type of approach may not produce results that are highly correlated with the hearing aid benefit experienced in everyday listening situations (Haggard et al., 1981; Berger and Hagberg, 1982; Oja and Schow, 1984). This is not too surprising, given the wide range of listening environments that a typical hearing aid user may experience during a day. It is also likely that the available clinical measures of speech recognition may not be sensitive enough to detect differences in performance produced by various types of signal processing.

To circumvent the limitations of these objective clinical measures, a wide variety of subjective measures of hearing aid benefit have been developed (see Weinstein [1997] for a review of this literature). The vast majority of these are self-assessment inventories that attempt to quantify hearing aid benefit across a range of everyday listening conditions. This approach has high content validity and studies have shown good test–retest reliability for adults (Cox and Alexander, 1995). In recent years, these types of metrics have gained increased use in clinical settings to document hearing aid benefit and to evaluate the efficacy of different types of signal processing.

For adults and older children, a wide variety of objective and subjective metrics are available to document outcome. The various tests can be used in isolation or in combination with other tests in order to answer a particular clinical question. However, much of the methodology and many of the metrics typically used with adults in the assessment of hearing aid benefit are not appropriate for use with infants and young children. Advances in the early identification of hearing loss have increased the need to make decisions early in life that are dependent upon demonstrating or failing to demonstrate device or treatment efficacy (e.g., sensory aid decisions, communication mode decisions). Appropriate amplification will contribute to the speech and language acquisition process by...
supporting the child in extracting the rules of phonology and syntax. To provide the best possible amplification device and take advantage of technological advances, there is a critical need for valid and reliable outcome measures for this population.

This paper is divided into five sections. In the first two sections, the unique needs of the pediatric population and factors complicating the measurement of outcome will be described in detail. The third section provides a review of literature on existing outcome measures for children. The fourth section will be devoted to a discussion of alternative approaches to document outcome. The final section will provide an overview of clinical and research needs in this area.

PEDIATRIC POPULATION: UNIQUE CHARACTERISTICS AND UNIQUE NEEDS

The process of fitting hearing aids to an infant or young child is qualitatively different than the adult case in a number of ways. Although newborn screening programs have enabled audiologists to identify hearing loss within the first few days of life, precise quantification of the degree and configuration of hearing loss may not be possible for many months. However, since recent data have shown that children with hearing loss who are involved in early intervention prior to 6 months of age outperform children who are not involved in intervention until later (Moeller, in press; Yoshinogo-Itano et al, in press), it is not considered reasonable to delay amplification until the child is capable of providing a comprehensive behavioral audiogram (Pediatric Working Group, 1996). For infants and older children with multiple disabilities, it is often necessary to select amplification characteristics based largely upon tone-burst auditory brainstem response (ABR) thresholds. Because only a limited amount of audiological information is available early on, hearing aid fitting schemes that require more than audiological thresholds cannot be used.

Even when behavioral measures can be obtained, the results differ substantially from the adult case. Test reliability may be affected by developmental issues, such as level of cooperation, attentiveness, and/or middle ear disease. Children's speech perception skills need to be measured within the confines of their receptive language abilities, which may limit the procedures that can be used and complicate interpretation of results (Boothroyd, 1991). Subjective feedback from the child will be minimal and informal observations by parents or other professionals often cannot be easily interpreted in terms of cause and effect.

Numerous physical differences exist as well. Both the ear canal resonance (Kruger, 1987; Kruger and Ruben, 1987) and the real-ear-to-coupler difference (Nelson Barlow et al, 1988; Feigin et al, 1989; Moodie et al, 1994) have been shown to vary as a function of age within the first few years of life. It is also likely that the average speech input level to the hearing aid microphone will be substantially greater for infants and toddlers than for adults due to proximity differences between parent and child in the first few years of life (Stelmachowicz et al, 1993).

At the present time, there are differing opinions and philosophies regarding the electroacoustic requirements for infants and young children. Some investigators have suggested that prescriptive hearing aid procedures developed for adults can be applied to young children (Byrne and Ching, in press; Jordt et al, in press). These investigators argue that the revised National Acoustics Laboratory (NAL) approach (Byrne and Dillon, 1986), which is based on the amplification of all speech bands to equal loudness, should be appropriate for hearing-impaired individuals of all ages.

Other investigators maintain that the amplification needs of infants and young children may differ from those of adults who generally acquire hearing loss in later life (Stelmachowicz, 1991; Seewald et al, 1996). Specifically, the latter investigators feel that the goal of amplification may be different for young children in that the hearing aids will be used for the development of language, speech perception, and speech production. Many of the available prescriptive procedures were based upon the preferred hearing aid characteristics of adult users or were validated in this group. Young children with hearing loss have not yet developed the linguistic and world knowledge that supports speech perception for adults in the form of contextual and redundancy cues.

Nittrouer and Boothroyd (1990) investigated the effect of context on the perception of four-word sentences in 4- and 5-year-old normal-hearing children and adults. The subject's task was to repeat both meaningful and nonmeaningful sentences presented at two different signal-to-noise (S/N) ratios. While the addition of context improved scores for both groups, the children showed significantly smaller improvements in
perception compared to the adults. These results suggest that, under adverse listening conditions, adults may be able to use contextual cues to “fill in the blanks” in a way that is not possible for young children. It follows that a less than optimal hearing aid fitting for an adult may not affect the perception of speech as much as would be the case for a child who is attempting to learn speech and language through audition.

In addition to these semantic differences, a number of investigators have shown that young children may differ from adults in their ability to use certain types of acoustic cues. Nozza et al. (1991) compared the discrimination thresholds of two speech contrasts (/ba/ vs /da/ and /ba/ vs /ga/) between 7- to 11-month-old infants and adults. The infants required stimulus intensities of 25 to 28 dB more than the adults in order to reach a criterion level of performance. It also appears that children tend to use slowly changing dynamic or temporal cues, whereas adults tend to rely more on static spectral cues (Morrongiello et al., 1984; Nitttrouer and Studdert-Kennedy, 1987; Nitttrouer, 1992).

Some investigators (Gatehouse, 1992, 1993) have shown that the speech perception performance of adult hearing-impaired listeners improves over time with repeated exposure to amplified speech. To date, there have been no systematic studies of acclimatization in young children. The existence of this phenomenon in children could have a potential impact on the ability to compare different types of signal processors during the hearing aid selection process. In addition, the use of vastly different types of processing schemes in multiple-memory hearing aids will alter the signal that is received by the child. Studies to determine the magnitude of acclimatization in the pediatric population and the clinical significance of the effects are needed.

The issue of which prescriptive procedure, if any, is optimal for young children has not been resolved. Ross and Levitt (1997) point out that, for many hearing-impaired individuals, virtually any type of amplification device will provide an improvement over unaided listening. As such, objective and/or subjective comparisons of unaided and aided benefit in no way guarantee that a hearing aid fitting is optimal. For young children, it may be extremely difficult, if not impossible, to ensure that a particular set of hearing aid characteristics is substantially better than other alternatives. A small number of studies have been conducted with preschool and school-aged children in which use gain or preferred gain was compared to the gain recommended by various prescriptive procedures with varying results (Snik and Homberger, 1993; Ching et al., 1994, 1996; Snik and Stollman, 1995; Snik et al., 1995). These types of studies are difficult to interpret because “use gain” will be highly dependent upon the rationale and procedures used to fit the hearing aid initially. Similarly, “preferred gain” may be biased by the characteristics of the initial fitting and the effects of acclimatization; if the child is accustomed to listening with particular frequency/gain characteristics, this response may be preferred over other alternatives in a paired-comparison task. In the absence of a consensus on how to determine optimal hearing aid characteristics for children, the need for valid and reliable outcome measures that can be applied on an individual basis is critical.

**PEDIATRIC POPULATION: FACTORS COMPPLICATING THE MEASUREMENT OF OUTCOME**

_What should be used as an outcome measure?_

Potential outcome measures include auditory awareness, audibility of speech, speech intelligibility, accuracy of speech production, rate of language acquisition, loudness discomfort, and social development. The metric selected will depend on both the age of the child and the degree of hearing loss and will be influenced by the age at which hearing loss identification occurs, concomitant middle ear problems, the existence of additional handicapping conditions, developmental factors, and the child's home and educational environments. The selected outcome measures also will depend upon the clinical question to be addressed. The question may be relatively broad, such as: What is the best hearing aid for a particular child? Or, given current hearing aid technology, more specific questions may be asked: Is a binaural or monaural fitting most appropriate for a child with an asymmetric hearing loss? Should a directional or omnidirectional hearing aid be recommended? How much high-frequency gain should be recommended for a child with a precipitous hearing loss? Should compression limiting (CL) or wide dynamic range compression (WDRC) be used for a child with a moderate-to-severe hearing loss? Under what conditions should a multimemory device be used and what hearing aid characteristics should be programmed into each memory? What real-ear saturation response will produce levels that are both safe and comfortable? Obviously, each of these questions may
require a different kind of outcome measure or some combination of measures.

**Over what time period should outcome measures be made?** With children, one would not expect to see immediate changes in speech production or language skills following the introduction of amplification or a change in hearing aid characteristics. Repeated auditory experiences or acclimatization (Gatehouse, 1993) also may be necessary in order to observe changes in speech perception. In most cases, longitudinal monitoring may be required to identify changes in performance that can be attributable to amplification (e.g., improved speech production of a now audible sibilant). The time frame for changes in behavior or performance is likely to be longer than is typical for an adult hearing aid user.

**How can ongoing developmental changes be separated from changes related specifically to amplification?** If it is necessary to use a longitudinal approach to document outcome, it may be difficult to separate the effects of normal development or the influence of other treatments (e.g., speech and language therapy) from the effects related to hearing aid use.

**At what developmental age will outcome measures developed for adults be valid for use with children?** For some subjective metrics it may be sufficient to alter the vocabulary, language level, and described situations to create an appropriate assessment tool. However, auditory goals and the child's ability to provide subjective feedback can be expected to change over time in a way that generally does not occur for adults. Thus, for most types of outcome measures developed for the pediatric population, it will be necessary to develop a series of metrics to reflect changes in performance as the child matures.

**CURRENT OUTCOME MEASURES**

**Objective Measures of Outcome**

For adults and older children, the most commonly used objective outcome measure is speech recognition. A wide variety of tests are available, measuring recognition of stimuli ranging from nonsense syllables to words and sentences. The materials, S/N ratio, and response format (closed set, open set) can be tailored to suit the specific objectives for each case.

Unfortunately, the situation is very different for young hearing-impaired children. Under the best of circumstances, it is not possible to obtain reliable measures of speech recognition for children less than 3 years of age. Beginning at about 3 years of age, the most commonly used clinical tests require the child to select the appropriate response from among a small set of pictures (e.g., Ross and Lerman, 1970; Katz and Elliott, 1978). While the words and pictures typically are within the repertoire of children in the 3- to 5-year age range, for hearing-impaired children, it is often impossible to separate factors such as auditory experience, participation in speech and language therapy, educational environment, and phonologic development from the true residual capacity of the damaged cochlea (Boothroyd, 1991; Boothroyd et al, 1996). That is, a young child's previous experiences will influence performance on this type of test and are likely to complicate the interpretation of results. If the goal of a test is to determine how well a child is performing overall, these interactions may not be a problem. If the intent is to assess the efficacy of a particular signal processing scheme, however, a valid test of auditory speech perception capacity should be devoid of lexical, syntactic, and semantic constraints. While nonsense syllables meet this goal, the use of these stimuli with young children is problematic in that it is difficult to provide an appropriate visual reference (e.g., written words, pictures) for each test item. An imitative test format has been developed for use in research studies with children as young as 3 years of age (Boothroyd, 1991; Boothroyd et al, 1996). In its current form, this procedure requires post-test editing of speech samples and scoring by a group of normal-hearing listeners; thus, it would not be applicable in a typical clinical setting.

Recently, Boothroyd (1991) has developed a PC-based video game (VIDSPAC) for evaluating the perception of various acoustic contrasts in children as young as 3 to 4 years of age. The program allows the child to select a colorful character to “present” the test stimuli and a wide range of speech pattern contrasts can be evaluated (e.g., vowel height, final consonant voicing). The child's task is to respond when a change in a string of stimuli is detected (/ta/, /ta/, /ta/, /da/, /ta/). Following each block of trials, an animated scene is displayed as a reward. In addition to the well-designed graphics, which are engaging for young children, the program has other features that are important for this population. The interstimulus interval can be varied during the experiment according to the child's needs and summary statistics provide an account of both hits and false positive responses. This type of test should be extremely useful in extending the lower age limit at which valuable estimates of
speech perception can be obtained from hearing-impaired children.

For older children, a much wider range of objective tests is available. These include tools that measure the perception of nonsense syllables, single words, sentences, and story comprehension. Special purpose materials are available for children with varying degrees of hearing loss and for auditory-alone versus auditory/visual perception. (See The Pediatric Working Group [1996] for a review of current speech tests for this population.) As previously mentioned, it is important to note the limitation of speech recognition as an outcome measure for both children and adults. While these objective tests can provide a quantitative estimate of performance that can be compared to expected goals, it is unlikely that these measures will be sensitive enough to compare different hearing aid characteristics.

Subjective Measures of Outcome

To date, only a small number of subjective tests are available for children and most of these have been developed for use in educational settings exclusively. The Hearing Performance Inventory for Children (HPIC), developed by Kessler et al (1990), is a self-assessment instrument for children (ages 8–14 years) that samples a child’s perceived communication difficulties in a variety of academic environments. The primary goal of this test is to develop a personal profile of difficult academic communication situations to aid in the design of an individualized management program. The test consists of 31 test items depicting a variety of typical classroom listening situations (e.g., hearing the teacher when his/her face is not visible). For each test item, a picture and a verbal description are given and the child’s task is to rate communication difficulty on a 5-point scale. In the development of the HPIC, test–retest measures were obtained on 15 normal-hearing and 7 hearing-impaired children, but no large-scale studies have been reported using this metric.

The Listening Inventories for Education (LIFE) were developed by Smaldino and Anderson (1997), also for use in the classroom. The LIFE consists of three inventories, one for the student and two for the teacher. The Student Appraisal of Listening Difficulty is intended to be used in a pre- and post-test format in order to document changes following intervention. It has 15 test items that are picture cards depicting different common listening situations in the classroom, chosen to be sensitive to the expected benefits of various forms of classroom amplification (e.g., hearing aids, personal FM systems, soundfield FM systems). The child’s task is to report the level of difficulty associated with each of the 15 different situations. Children in grades 1 to 3 use a 3-point scale and older children use a 5-point scale. The Teacher Appraisal of Listening Difficulty is designed to be given after intervention and consists of 16 questions related to specific areas of improvement in either behavior or communication. The Teacher Opinion and Observation List consists of four items in an open-ended format. Test–retest reliability of the student questionnaire was assessed with 19 normal-hearing third and fourth graders over a 1- to 3-week period. No significant differences were observed between the scores for any of the test items. These inventories are flexible and can be used in a variety of ways (e.g., document efficacy of amplification or classroom teaching methods, inservice training of teachers, self-advocacy).

The Screening Instrument for Targeting Educational Risk (SIFTER) (Anderson, 1989) was developed to identify school-aged children who are at risk for educational failure due to hearing loss and thus in need of further evaluation. This 15-item test is completed by the child’s teacher and covers five content areas: academics, attention, communication, class participation, and school behavior. Teachers use a 5-point scale to evaluate a child using items such as “How distractible is the student in comparison to his/her classmates?” The total score in each content area is categorized as either a pass, fail, or marginal outcome. A preschool version (3 years–kindergarten) of this test has also been developed (Anderson and Matkin, 1996). While this test was designed as a screening tool, it can be used to assess the efficacy of various forms of intervention in the classroom (e.g., preferential seating, soundfield amplification, FM systems, personal amplification).

Recently, Kopun and Stelmachowicz (1998) adapted the Abbreviated Profile of Hearing Aid Benefit (APHAB), developed by Cox and Alexander (1995), to be appropriate for children in the 10- to 15-year age range. Children with both moderate and severe hearing losses showed a pattern of responses across the four subtests of the APHAB that was similar to the aided adult data reported by Cox and Alexander and test–retest reliability over a 2- to 3-month period yielded correlation coefficients in the 0.83 to 0.95 range. Parents also were given the test in order to assess the parent’s perception of the
child’s communication problems. Interestingly, the correlations between the child and parental scores on all four subscales were quite low. That is, for this group of subjects, the parents and children did not agree with respect to communication difficulties. No obvious trends were observed and it is unclear whose impression best reflects the degree of difficulty actually encountered. It is possible that the parents may have noticed communication difficulties that were not apparent to the child. It is also possible that parents of children in this age range may have had limited opportunities to observe their child in the variety of communication situations described in the questionnaire. These results raise an important issue regarding the development of subjective measures for use with the pediatric population. Can parents, caregivers, or other individuals provide a valid estimate of communication difficulties via observation?

The Meaningful Auditory Integration Scale (Robbins et al, 1991) is a parent report measure designed for use with profoundly hearing-impaired children. This tool consists of 10 questions that include items on device acceptance and use, awareness of familiar environmental sounds, and the ability to distinguish speech from nonspeech stimuli. Parents use a 5-point scale in responding to each test item. This test is most appropriate for young children with profound hearing loss as ceiling effects are observed for children with greater residual hearing.

It may be possible to modify some existing subjective tests for use with young children. Moeller (1993) has suggested that modification of the Client-Oriented Scale of Improvement (COSI) described by Dillon et al (1991, 1997) might be appropriate for infants and toddlers. In its original form, the COSI is designed to allow the patient to select up to five situations in which communication is difficult. Following a trial period with amplification, the patient estimates the degree of change relative to the unaided situation using a 5-point scale. This is an efficient way to assess outcome because the questionnaire is individualized to focus on the specific goals of the patient. Because the goals differ from case to case, however, findings cannot be easily grouped across subjects. Potentially, this approach may prove to be very useful for young hearing-impaired children because individual situations and goals are likely to differ substantially across children, even when they have similar hearing losses. Furthermore, goals are likely to change relatively often in the first few years of life as speech and language skills develop. For an infant with a newly identified hearing loss, initial goals may include auditory awareness and alerting to familiar environment signals. By 9 to 12 months of age, more specific goals may be appropriate such as differentiating certain sounds or words. This type of approach may require clear and structured guidelines for parents and other caregivers to ensure that their observations are unbiased and focused appropriately on the specific goal.

**ALTERNATIVE APPROACHES**

It should be obvious that the documentation of hearing aid efficacy in the pediatric population is extremely complex. For a variety of reasons, it is unlikely that a single outcome measure or a single approach to the problem could provide a means by which to determine efficacy in all cases. The following alternative options are described in detail along with the assumptions and rationale for each approach.

**Studies of Device Efficacy**

For most hearing aid fittings, a wide range of options (e.g., frequency response, gain, circuit type) are available and it would be impossible to entertain all options during the evaluation process. Studies of device efficacy with well-defined groups of subjects can help provide guidelines to indicate when certain types of technology may be most appropriate. For example, laboratory studies of adults with mild-to-moderate hearing loss have shown that directional microphones can improve the S/N ratio by 5 to 7 dB over omnidirectional microphones (Hawkins and Yacullo, 1984; Valente et al, 1995). If a particular hearing aid circuit or characteristic is shown to be efficacious for a given group of hearing-impaired individuals, then it can be assumed that the feature would be efficacious in individual cases.

To date, only a few studies of this type have been conducted with children. Christensen and Thomas (1997) compared the performance of peak clipping (PC), CL, and WDRC in 9- to 14-year-old children with mild-to-moderate hearing loss and found significantly better speech recognition with WDRC and CL compared to the PC circuit. Significant differences in perception were not observed between the WDRC and CL circuits. In the second part of this study, a multiple-memory device was programmed with the three circuit types and the children
wore the hearing aids for 2 months, recording preferred memory settings in a diary. WDRC was preferred most often in noise and CL was preferred most in quiet. The children reported subjective benefit from the use of multiple memories in different listening environments. Seewald et al (1997) measured speech recognition and aided loudness growth in a group of adolescents using both linear and WDRC hearing aids. They found better speech recognition over a wider range of input levels with WDRC compared to linear processing. In addition, WDRC produced loudness growth functions that closely approximated normal loudness growth.

Gravel et al (in press) investigated the efficacy of dual-microphone technology for children in the 4- to 6- and 7- to 11-year age ranges. For the perception of single words, the directional microphone advantage was similar for both groups (an effective improvement in S/N ratio of ~4.8 dB). For sentence materials, the younger group demonstrated an advantage of 4.3 dB and the older group showed an advantage of approximately 5.2 dB. These values are lower than those reported for adults (approximately 8.0 dB) using the same type of dual-microphone technology (Valente et al, 1995).

Laboratory studies of device efficacy in specific populations can play an important role and have some advantages over individual measures of outcome. In these types of studies, the necessary variables can be controlled, thus facilitating the interpretation of results.

### Audibility of Speech: Predictive Measures

While factors such as frequency or temporal resolution and abnormal growth of loudness may play a role in speech perception, numerous studies have suggested that the primary factor responsible for speech recognition problems in individuals with hearing loss is the reduction in signal audibility (Pavlovic, 1984; Humes et al, 1987; Zurek and Delhorne, 1987; Humes, 1991). As such, measures of the audibility of speech under various aided conditions may provide a basis for determining efficacy of a particular hearing aid fitting. Both the Desired Sensation Level (DSL) fitting procedure for linear hearing aids (Seewald, 1992) and DSL i/o (Cornelisse et al, 1995) for nonlinear hearing aids provide a graphic display of the audibility of average speech across frequency. As shown in Figure 1, this display can provide a visual reference to aid in the finetuning of a hearing aid fitting. In this figure, the open squares represent auditory thresholds, the filled triangles represent the predicted upper limit of comfort, and the three dashed curves show the target values for soft, average, and loud speech.

![Figure 1](image)

**Figure 1** Graphic display from DSL i/o (Cornelisse et al, 1995). The open squares represent auditory thresholds, the filled triangles represent the predicted upper limit of comfort, and the three dashed curves show the target values for soft, average, and loud speech.
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and the associated aided audibility index (AAI) is displayed. Such an approach can provide a quantitative way to compare audibility across hearing aids or across situations.

It is important to note that the aided audiogram or functional gain measures often cannot provide a valid representation of the audibility of speech at typical input levels (Macrae and Frazier, 1980; Macrae, 1982; Stelmachowicz and Lewis, 1988). This is particularly true for wide dynamic range hearing aids where the measured gain varies as a function of input level.

**Paired-Comparison Measures**

A number of investigators have used a paired-comparison approach to evaluate differences perceived in various hearing aid characteristics by children. Eisenberg and Levitt (1991) investigated the feasibility of using a paired-comparison task to select hearing aids for children. Children with mild to moderately severe hearing loss judged the clarity of a children's story that had been filtered with nine different frequency-gain shapes. They found the technique to be feasible for hearing-impaired children as young as 6.5 years of age. Ching et al (1994) used a paired-comparison procedure with a group of 21 children (ages 6–19 years) with severe to profound hearing losses. The purpose of the study was to evaluate the reliability and sensitivity of intelligibility judgments under audiovisual and auditory-alone conditions. Results showed that the method could be used reliably with subjects as young as 6 years of age and that the mode of presentation had little effect on the results. Recently, Stelmachowicz et al (in press) used a paired-comparison procedure to assess quality differences between speech processed by either CL or PC. The frequency/gain and output characteristics were selected to reflect a typical state-of-the-art hearing aid fitting; thus, the acoustic differences across stimuli were subtle compared to many earlier studies of this nature. Normal and hearing-impaired subjects in three age ranges (7–9 years, 10–12 years, and adults) were tested. While the normal-hearing adults and the 10- to 12-year-old children were able to distinguish between the stimuli, the youngest normal-hearing group and both groups of hearing-impaired children were relatively insensitive to these acoustic differences. These investigators suggested that the reliability and validity of paired-comparison measures may depend upon the magnitude of the physical differences between the stimuli to be compared. That is, it may only be possible to use this technique with young children when the perceptual contrasts to be compared are relatively large.

**Loudness Measures**

While many prescriptive hearing aid methods provide recommended real-ear saturation levels, these levels are based on average data. Hawkins et al (1987) have suggested that hearing aid rejection is often based on loudness discomfort. A small number of studies have been reported in which measures of loudness discomfort level (LDL) have been attempted in young children. Kawell et al (1988) evaluated hearing-impaired children in the 7- to 14-year age range and reported across-session intra-subject standard deviations that ranged from a low of 3.0 dB at 500 Hz to 5.8 dB at 3000 Hz. Stuart et al (1991) also evaluated 7- to 14-year-old hearing-impaired children and their within-session intra-subject standard deviations were slightly lower (3.4–4.9 dB). Compared to adult data, these values are within 1 dB of the standard deviations reported by Cox (1981) but are 4 dB greater than those reported by Hawkins et al (1987). Macpherson et al (1991) evaluated LDLs in a younger group of normal-hearing children (3–5 years) and concluded that only children with mental ages > 5.0 years could perform this task reliably.

Teghtsoonian (1980) applied a cross-modality matching technique to loudness scaling in 4- to 12-year-old normal-hearing children and adults. Children were asked to match the loudness of a 1000-Hz tone to the length of a retractable tape. The slope of the function relating intensity to length was invariant across all ages, but the intercept differed significantly between the 4 and 6 year olds and the older subjects. That is, at a given intensity, the younger subjects selected a shorter length than did the older subjects. By 8 years of age, both the slope and the intercept approximated adult values. Since developmental changes did not alter the slope of the functions, the author concluded that cross-modality matching can be used successfully in children as young as 4 years of age. Despite the clinical use of loudness growth measures to assist in the fitting of nonlinear hearing aids for adults, no systematic studies with young hearing-impaired children have been reported.
Figure 2 Graphic display from the Situational Hearing Aid Response Profile (Stelmachowicz et al, 1996). Xs represent auditory thresholds, asterisks show the maximum output, and the cross-hatched region shows the audible region of speech. The shaded region (lower left panel) denotes peak clipping. An aided audibility index (AAI) is displayed in each panel.

CLINICAL INNOVATION AND RESEARCH NEEDS

Speech Recognition Tests

There is a great need for more sophisticated approaches to the measurement and quantification of speech recognition abilities in young children. A developmentally appropriate battery of measures that considers the symbolic and attentional demands of young children is needed. While interactive video technology may be promising with children > 3 years of age, the clinical measurement of speech recognition during infancy is problematic. Laboratory studies using visual reinforcement techniques (Kuhl, 1983) have shown that normal-hearing infants are capable of recognizing a variety of acoustic differences. At present, these techniques have not been adapted for use in clinical settings.

Many of the current tests that are available for children > 3 years of age are somewhat outdated both in terms of the pictorial representations and vocabulary. Within this age range, there is also a need for tests that would focus on the type of speech recognition problems experienced by children with mild hearing loss or hearing loss restricted to the high frequencies.
Subjective Inventories

As noted earlier, a small number of inventories have been developed for use with school-aged children in academic settings. There is a need for additional inventories that focus on specific listening situations outside the classroom. Studies are needed to determine the lower age limit at which pictorial representation and/or simple descriptions of listening situations (e.g., listening to television with other children talking) can provide both valid and reliable data.

Parental Inventories

Parental inventories are widely used and well accepted in a number of fields (e.g., speech-language pathology, psychology, pediatrics) in order to document developmental milestones, abnormal behavior, and a variety of other factors. Indeed, portions of many current developmental metrics include test items that may be used to document auditory behaviors. Unfortunately, no single metric has been developed that focuses exclusively on the auditory behaviors of infants and young children and on the expected benefits to be derived from amplification. These types of measures may be the only alternative for use with infants and toddlers. There is a need to develop clearly focused measures that will allow us to infer some probabilistic cause and effect relationship with amplification.

Modify Existing Subjective Procedures (e.g., Loudness Growth, Quality Judgments, Preferred Frequency Response)

While some progress has been made in this area, more studies are needed to determine if procedures designed for adults can be modified to provide valid and reliable data in young children. The degree of success for any particular procedure is likely to be influenced by the degree of hearing loss, cognitive development, and the child's attention span, as well as the design features of the task and the stimuli used.

Identify Objective Correlates

As the age at which the identification of hearing loss and the initiation of amplification decreases, the need for objective measures of performance increases. There is a need to identify objective measures that correlate highly with the perceptual measures that can only be obtained reliably from adults and older children. For example, ABR thresholds have been shown to agree well with behavioral results (Stapells et al, 1995), thus allowing hearing aids to be fitted within the first few weeks of life. It may be possible to use electrophysiologic measures to provide suprathreshold measures of auditory function. Boothroyd (1991) has suggested that it may be possible to develop objective tests, using evoked potential techniques, to measure differential responses to various acoustic contrasts, thus providing an estimate of the auditory capacity for speech perception.

SUMMARY

The documentation of hearing aid efficacy in young children is a complex issue confounded by a variety of variables. While some progress has been made in recent years, there is a great need for additional work in this area. It is likely that a battery of measures, adapted to certain age ranges, will be required. Parent report measures may have a significant role to play with the youngest children with more reliance on direct measures as children mature. In test development, both the symbolic and attentional constraints of children must be considered. It also will be important to develop test items that focus on the specific benefits to be expected from various forms of amplification if children are to take advantage of emerging technologies.

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