PEDIATRIC AMPLIFICATION PROTOCOL

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PURPOSE

The purpose of this document is to provide a detailed guideline related to what children should be considered for amplification, what data are necessary to start and continue the amplification process, how essential features of the amplification system should be chosen, what testing should constitute verification and validation of the amplification system, and suggestions for appropration orientation, training, and follow-up. These guidelines are meant to cover the newborn, infant, and child. These guidelines are not meant to suggest appropriate communication modes or academic settings for these children. In addition, children may have a variety of other co-existing conditions with hearing loss and these guidelines must be considered within the context of each child's circumstances. The general goal of any hearing aid fitting is to provide a signal that makes soft, moderate, and loud sounds audible but not uncomfortable and provides excellent sound quality in a variety of listening environments.

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1. Personnel Qualifications

a) Audiologists are the professionals singularly qualified to select and fit all forms of amplification for children, including personal hearing aids, frequency-modulated (FM) systems, cochlear implants and other assistive listening devices (The Pediatric Working Group, 1996). Audiologists have a master's and/or doctoral degree in audiology from a regionally-accredited university.

b) Audiologists must meet all state licensure and/or regulatory requirements.

c) Audiologists fitting hearing aids on infants and young children should have the expertise and the test equipment necessary to complete all tests for hearing aid selection, evaluation, and verification procedures described herein.

d) Audiologists should adhere to procedures consistent with current standards of practice to assess auditory function in infants and children (Audiology Clinical Practice Algorithms and Statements, 2000).

e) Audiologists should be knowledgeable about federal and state laws and regulations impacting the identification, intervention, and education of children who are deaf and hard of hearing.

2. Candidacy

a) Introduction

Amplification with hearing instruments should be considered for a child who demonstrates a significant hearing loss, including sensorineural, conductive, or mixed hearing losses of any degree. The duration and configuration (bilateral or unilateral) will assist the audiologist in the decision to fit a child with personal hearing aids. Additional factors such as the child's health, cognitive status, and functional needs also will influence the time-line of fitting hearing aids.

b) Methods for the assessment of hearing

For newborns and infants under the developmental age of 6 months, estimates of hearing sensitivity must be supported by electrophysiological measures including auditory brainstem response (ABR) threshold assessment. Frequency-specific air-conduction and bone-conduction ABR thresholds should be obtained. Frequency-specific ABR is necessary for accurate estimation of the degree and configuration of hearing loss. A click-ABR threshold alone is not sufficient for accurate hearing aid fitting. Acoustic immittance measures, including tympanometry and middle ear muscle reflexes, and otoacoustic emissions (OAE) are necessary to determine the type of hearing loss present.

Differential diagnosis continues to be refined and these measures should be applied to the assessment of hearing in children as they become available and interpretable. Currently researchers are suggesting that the summating potential may have value in diagnosis and that a lack of response in this measure may relate to inner hair cell function. These and other electrophysiologic measures may become a valued part of the assessment of hearing in the pediatric population. At a minimum, low and high frequency, ear specific information should be obtained in order to prescribe appropriate amplification. These data are developed over the course of evaluating the infant or child and the hearing aid fitting may begin before all data are obtained.

For older infants and young children, behavioral thresholds should be obtained using visual reinforcement audiometry (VRA), or conditioned play audiometry (CPA) test techniques appropriate for the child's developmental level. Ear-specific and frequency-specific air and bone conduction thresholds are essential for providing information needed for accurate hearing aid fitting (The Pediatric Working Group, 1996).

c) Additional factors

1) Middle Ear Conditions
The presence of chronic or recurrent middle ear conditions that can affect hearing threshold results or the ability to wear an occluding earmold should be considered. When determining hearing aid candidacy for infants or children with borderline or minimal hearing losses, middle ear status is of particular concern in determining the likelihood of a transient condition.

2) Other Health Concerns
Other health concerns or conditions that may affect the ability to obtain reliable threshold information must be considered. The use of physiologic test methods (ABR, OAE) may be necessary even with older children who have additional disabilities.

d) Special Considerations

Special consideration should be given to the fitting of amplification on children with unilateral hearing loss, minimal or mild hearing loss, profound hearing loss, and auditory neuropathy

1) Unilateral hearing loss
Use of hearing aid amplification is indicated for some children with unilateral hearing losses. The decision to fit a child with a unilateral hearing loss should be made on an individual basis, taking into consideration the child's or family's preference as well as audiologic, developmental, communication, and educational factors. Amplification options such as personal FM systems also should be considered. Use of communication strategies (noise reduction, positioning, etc.) may prove to be beneficial and easily accomplished for the infant or toddler with unilateral hearing impairment. The use of Contralateral Routing of Signal (CROS) amplification requires particular care. Its design is to overcome the problem caused by the head shadow effect. This could be especially helpful in a quiet environment and when the signal of interest originates from the direction of the nonfunctioning ear. However, one recent study (Kenworthy, Klee, & Tharpe, 1990) indicated that CROS amplification

may not be beneficial for children in a classroom setting, because of the introduction of additional noise to the normal-hearing ear.

2) Minimal-mild hearing loss
Current evidence suggests that children with minimal and mild hearing losses are at high risk for experiencing academic difficulty (Bess, Dodd-Murphy, and Parker, 1998; Bess and Tharpe, 1984). As such, children with minimal and mild hearing loss should be considered candidates for amplification and/or personal FM system or soundfield systems for use in school.

3) Profound hearing loss
A finding of no response by ABR should not exclude a child from hearing aid candidacy, as residual hearing may exist at intensity levels greater than those capable of eliciting a standard ABR response. Children with confirmed profound hearing loss still may experience benefit from hearing aid amplification. An infant or child with severe to profound hearing loss is a cochlear implant candidate.

4) Normal peripheral hearing sensitivity
In some cases, children with normal peripheral hearing sensitivity may benefit from amplification (Matkin, 1996). These cases may include children with auditory processing disorders (APD), auditory neuropathy (AN) or dysynchrony, and children with unilateral hearing impairment when an FM system is coupled to the normal-hearing ear. In such cases, close audiologic monitoring of hearing sensitivity, and careful control of the output of the amplification is required.

3. Pre-Selection Issues and Procedures

a) Introduction
Many decisions must be made prior to selecting amplification for a child. These decisions may be based on individual needs and abilities, diagnostic information (e.g., degree of hearing loss, physical characteristics, etc.), environment in which the individual functions, empirical evidence, and/or clinician experience. Many of these decisions must be revisited on an ongoing basis as the child matures.

b) Air vs bone conduction
Air conduction hearing aids are considered the more conventional hearing aid type and provide amplified sound into the ear canal of the user. A bone conduction hearing aid typically is considered for children who are unable to wear air conduction devices as a result of malformation of the outer ear or recurrent middle ear drainage. A bone conduction hearing aid may be considered for children with unilateral conductive hearing loss to insure that the intact cochlea on the side with the conductive hearing loss is stimulated during development while waiting for corrective surgery. The bone anchored hearing aid is a device that is

surgically implanted into the skull behind the ear and produces a bone conducted signal that is transmitted through the skull to the inner ear. This type of device is useful for an individual who must use a bone conducted rather than an air conducted signal on a permanent basis. At this time, bone anchored hearing aids do not have the approval of the U.S. Food and Drug Administration (FDA) for use in children less than five years of age. A bone anchored hearing aid may be considered as an option for an older child.

c) Style: body aid vs. behind-the-ear (BTE) vs. in-the-canal (ITE) vs. in-the-canal (ITC) vs. completely-in-the-canal (CIC)
Style will be dictated by the child's hearing loss and potential for growth of the outer ear and individual needs. The outer ear may continue to grow well into puberty, thus dictating the BTE style. When growth occurs, only the earmold has to be replaced. The BTE is more durable (with no circuitry directly exposed to cerumen) than in-the-ear styles, is less likely to produce feedback when fitted with an appropriate earmold, and allows for a variety of features that may be essential for the child (i.e., telecoil circuitry, direct audio input connection, built-in FM circuitry). An in-the-ear or even completely-in-the-canal hearing aid may be an option for older children as long as the audiologist, child, and parents recognize the pros and cons of each style (e.g., increased cost, lack of DAI coupling to assistive technology, susceptibility to damage, etc.).

As more infants are identified at an earlier age as a result of universal newborn screening, the audiologist is faced with placing a BTE case on a very small pinna often resulting in feedback. To alleviate feedback the audiologist may want to consider coupling an assistive listening device to the BTE hearing aid. The microphone is then placed near the speaker (connected to a transmitter). The desired signal is sent to the receiver (near the child) and the sound is coupled to the hearing aid through direct audio input or telecoil. Because of the distance between the microphone and the receiver, feedback is greatly reduced. This solution, however, eliminates the infant's ability to monitor his/her own voice because the microphone of the hearing aid has been turned off.

d) Routing of the Signal
   1) Bilateral vs unilateral listening
      It is well documented that bilateral hearing is necessary for localization and for best performance in noise (Hawkins & Yacullo, 1984; Valente, 1982a, 1982b). In addition, investigations have reported auditory deprivation in children fitted with unilateral amplification (Boothroyd, 1993; Hattori, 1993). Therefore, it is recommended that, unless contraindicated, children be fitted with bilateral amplification.

   2) CROS, BICROS, transcranial fitting
      For children with severe to profound unilateral hearing loss (or very poor word recognition unilaterally), Contralateral Routing of Signal (CROS) system may be considered. A CROS system can be achieved by putting a

microphone at the location of the impaired ear and transmitting the signal to the normal ear through:

1) a wire or FM signal (conventional CROS),
2) through bone conduction

For the child with severe to profound hearing loss (or very poor word recognition) in one ear and an aidable hearing loss in the other ear, a BICROS system may be considered.

3) Implantable devices
No middle ear implantable devices for children are available at this time.

e) Receiver type
There are data that suggest that the Class D (or B) receiver is far superior to the Class A receiver in terms of sound quality (Johnson, Killion, 1994; Palmer, et al., 1995).

f) Bandwidth
Research in adults supports the use of a wide bandwidth for individuals with mild to moderate hearing losses (Skinner, 1983). A number of investigators have studied bandwidth effects in adults with moderate-to-severe hearing loss (Ching, Dillon, & Byrne, 1998; Hogan & Turner, 1998; Turner & Cummings, 1999). These studies suggest that the provision of high-frequency amplification may not always be beneficial and can even degrade speech perception for some individuals. In these studies, there is considerable variability in performance across individuals and no consensus on the degree of hearing loss at which benefit from high-frequency amplification no longer occurs (Moore, 2001). Kortekaas and Stelmachowicz (2000) and Stelmachowicz, Pittman, Hoover, and Lewis (2001) found that hearing-impaired children require a wider bandwidth than adults with similar hearing losses to perceive high-frequency speech sounds, particularly when listening to female and child talkers. Ching, Dillon, and Katsch (2001) indicate that there is no conclusive evidence in this area at this point and time. Therefore the clinician must consider each child as an individual as we wait for more evidence in this area. In addition, the clinician should not confuse a lack of increased performance with high frequency amplification with an actual decrease in performance.

g) Memories
Memories allow more than one amplification characteristic for use by the wearer in different listening situations. The user (or parent) can choose among memories based on the listening situation. In the pediatric population, multiple memories may be very useful if there is a predictable fluctuating hearing loss so that the hearing aid output can be easily adjusted accordingly. In addition, a programmable telecoil memory will also be useful.

h) Earmold

The audiologist should consider the style, material, color, length, and frequency of remakes for the earmold. The need for excellent fitting earmolds has increased with the advent of wide dynamic range, wideband hearing aids. The audiologist is able to make a wide range of sounds audible in an automatic way by using compression circuitry with no volume control. Without a volume control, the child (or parent) cannot turn down the hearing aid if it starts to feed back as a result of poor earmold fit (after growth of the outer ear). The use of automatic technology forces the audiologist to be more proactive about regular earmold changes. The recent advent of automatic feedback control through various digital signal processing techniques may alleviate this problem temporarily while the new earmold is ordered. For infants, earmold replacement may be as frequent as monthly.

Venting in the earmold may be appropriate for some children depending on the configuration and degree of hearing loss as well as the status of their outer and middle ear. The audiologist should approach venting earmolds in children cautiously. Diagonal venting may cause the hearing aid to lose some of its high frequency response and certain placements of venting may create problems in sound channel tubing retention.

i) Sound channel

The sound channel consists of the earhook and tube that leads through the earmold and sends sound into the ear canal. Just as a horn (increased diameter at the end of a sound channel) increases the high frequency response, a reverse horn will roll off the high frequencies. These are often the frequencies where the child needs the most amplification. A reverse horn is a common concern in an infant or young child because the earmold is so small. It is essential that the end of the sound channel be checked visually for any crimping. An electroacoustic measure that includes the earmold will reveal any roll off in high frequency response as will probe microphone measurements that include the individual's earmold connected to the hearing aid.

Manufacturers generally send adult size earhooks unless otherwise instructed. A pediatric earhook can be the difference between a well situated BTE and a BTE that falls off of the ear. Earhooks add resonant peaks to the hearing aid response. These peaks can increase the chance of acoustic feedback and may dictate the maximum output setting of the hearing aid thereby unnecessarily decreasing the headroom (the difference between the level of speech and the saturation level of the hearing aid) of the instrument. A filtered (damped) earhook will smooth the response (Scollie & Seewald, 2002).

j) Microphone

Microphone location impacts the response of the signal that is presented to the ear. For most pediatric users, the microphone will be at the top of the ear because they will use the BTE style.

The BTE and ITE styles can be equipped with omni-directional microphones (microphones that respond to signals equally around the head) or directional microphones (microphones that reduce signals from the sides and back). Directional microphones can enhance hearing in noise in adults (Hawkins & Yaccullo, 1984). The user may switch between microphone types by using a toggle switch, button, or remote control device. This is not a realistic choice for infants and young children. The use of a traditional directional microphone also implies that the signal of interest is in front of the listener. Young children learn by listening to the adults around them and may not be looking at them directly. In such situations, there may not be a primary talker. In some of the newest digital hearing aids, this switching occurs automatically based on a sampling of the incoming signal. Type of microphone technology will be dictated by the age and abilities of the child as well as listening environment. Benefits and limitations of directional microphone technology with children are currently unknown. Through the selection and deselection of memories, some hearing aids allow the audiologist to choose when to introduce the use of directional microphone technology (activating the programmable memory), thereby equipping hearing aids with potential that may not be used right away with a young child. When directional microphones are used with older children, the audiologist should ensure that the microphone response in the directional setting is equalized to the microphone response in the omnidirectional setting or audibility for low frequency sounds is lost (Ricketts,& Henry, 2002).

k) Controls for fine-tuning
With children, it is frequently necessary to conduct fine-tuning of the hearing aids' gain and output characteristics. The audiologist often has more flexibility in fine-tuning with programmable instruments than with potentiometers (screw-driver controlled). As more and more infants are fitted with hearing aids as a result of universal newborn screening, the use of flexible technology becomes even more critical. The hearing abilities of these babies continue to be defined as they mature and flexible hearing aids can be changed to reflect the new information obtained from the diagnostic procedures. In addition, children may have progressive hearing losses. A flexible hearing aid is a cost-effective solution for these children because the response of the hearing aid can be changed to meet the child's needs as the hearing loss changes or as more complete information is obtained.

l) Previous Experience
The audiologist's decisions for all of the features described in this section may be impacted by the child's previous experience. Only the older child will have previous experience, but the impact of previous experience should be considered when working with the infant. There are data to suggest that hearing aid users will become accustomed to whatever signal processing they experience and will come to prefer it (Palmer, 2001). This puts a great deal of burden on the audiologist to provide the very best audibility and sound quality to the first-time

user as this is the signal to which he/she will adapt. This is not to say that a current user of one technology (e.g., linear processing) cannot adapt and benefit from another technology that the audiologist may deem appropriate at the time of a replacement hearing aid fitting (e.g., wide dynamic range compression). Children may require an adjustment period before they tolerate and benefit from the newer technology, just as we expect adjustment to frequency transposition, cochlear implant signal processing, etc.

m) Telephone Access
The Developmental Index of Audition and Listening (Palmer & Mormer, 1999) illustrates that the telephone is an integral part of a child's life from the time when they know that someone is calling, extending through their attempts to participate in telephone communication with a parent's help, to the time when they are using the telephone to make plans with their friends. It is essential that the audiologist provide telephone access for even the youngest hearing aid wearers and take the time to educate the parents on how the solution works (this may take a variety of training sessions until the parents or guardians are comfortable).

n) Ability to couple to assistive listening technology
The child's hearing aids may be coupled to assistive technology through the telecoil, direct audio input, built-in FM receiver, or FM receiver attachment. The assistive listening device will be the best solution for listening in noise and/or listening at a distance. Selection of instruments that are compatible with FM systems, particularly the specific FM system provided at school may be warranted. It is critical to know the coupling requirements of the school system.

o) Battery Doors
The audiologist should recommend tamper-resistant battery doors for younger children.

p) Volume control
The need for a volume control is dictated by the signal processing scheme that is used in the hearing aid and the user's previous experience (if any). If the audiologist does not expect the child to make these adjustments, wide dynamic range compression signal processing will be advantageous.
Adjustment of a volume control wheel can provide a short-term solution to feedback caused by poorly fitting earmolds. If a volume control is present, the clinician must decide if the child should have access to manipulating the control or if a locking volume control is preferred (access is then limited to the clinician and perhaps parent/caregiver). Linear signal processing implies that a volume control is not only included, but is manipulated since the gain for a linear system is targeted to moderate level input signals. One assumes that the user would need to turn down more intense inputs and turn up quiet inputs to maintain audibility and comfort.

The unique combination of the above decisions will lead to the selection of particular hearing aids for a particular child. Some decisions exclude other choices and a compromise may have to be reached by prioritizing these choices.

4. Circuitry—Signal processing

Although certain signal processing schemes require digital processing, the discussion here is only relevant to the strategies, not digital versus analog processing to implement those strategies. That is, the appropriate signal processing question is not, in our opinion, whether we should select digital or analog hearing aids, but rather, what signal processing schemes are appropriate. In some cases the desired signal-processing scheme may require digital signal processing, in other cases it may not. It is likely that all hearing aids will be digital within the next five years and the analog vs digital decision will be irrelevant. The choice of appropriate features for each individual will be paramount.

a) Basic Requirements

1) The system should avoid distortion.
2) The system should allow frequency/output shaping to provide audibility based on an appropriate prescriptive method.
3) The system should allow frequency/output shaping to avoid tolerance issues based on an appropriate prescriptive method.
4) The system should employ amplitude processing that ensures appropriate audibility over a range of typical speech sounds from soft to loud. It is likely that some form of amplitude compression may be necessary to achieve this goal for the common cases of reduced residual dynamic range of hearing. Wide-dynamic range amplitude processing may routinely be necessary to allow for optimal audibility of soft to loud inputs (Jenstad, et al., 1999, 2000).
5) Output limiting is independent of the signal processing that is provided in the dynamic range. Compression output limiting has been shown to provide superior sound quality as compared with peak clipping output limiting (Hawkins & Naidoo, 1993; Preves & Newton, 1989).
6) The system should include sufficient electroacoustic flexibility to allow for changes in required frequency/output characteristics related to growth of the child (e.g., a larger ear canal will result in a smaller real-ear-to-coupler difference, etc).

b) Current and Future Processing Schemes - Until sufficient data become available to exclude the following schemes, each should be considered viable for pediatric fitting of hearing aids.

1) Automatic feedback control, to allow for use of amplification while the child or infant is held or placed in close proximity to other objects. Caution is advised in cases in which the hearing aid requires a gain

reduction in order to prevent feedback. In such cases, the potential loss of audibility of important sounds must be considered.

2) Multiple channels to allow for finer tuning of the response for fitting unusual or fluctuating audiograms, application of wide dynamic range compression, increasing the specificity of noise reduction, allowing specialized feedback and occlusion management.
3) Expansion to reduce low-level noise (e.g., microphone noise and over-amplification of soft sounds associated with very low-threshold compression).
4) Compression to allow fitting of the large variation of input levels found in speech and environmental sounds into the dynamic range of the child with hearing loss. Compression also is used as a limiter, providing comfort and good sound quality for the output of intense signals.
5) Frequency transposition and frequency compression have yet to be sufficiently validated. This type of signal processing might be recommended only when the frequencies to be transposed cannot be made audible with non-transposing aids.

c) Many schemes under development to reduce background noise (e.g., envelope modulation counters [digital noise reduction]) and/or enhance speech perception (e.g., spectral enhancement, temporally or spectrally based selective speech enhancement) cannot be recommended until data relative to their effectiveness become available.

5. Hearing Instrument Selection/Fitting Considerations in Children

During the selection process, a determination of appropriate circuitry and processing schemes should be based on the degree, configuration, and type of hearing impairment as well as consideration of familial and economic factors. Selection and verification protocols are predicated on the availability of frequency-specific threshold data.

a) Individual or age appropriate ear acoustics should be accounted for in the hearing instrument selection fitting process. Measurement and application of the real-ear-to-coupler-difference (RECD) accomplishes this goal (Moodie, Seewald & Sinclair, 1994). Real-ear-coupler-differences are used to individualize the HL to SPL transform. This is important in a population whose earcanals and eardrum impedance generally are different from the adult averages that typically are used to conduct these transforms (Scollie, et al., 1998; Seewald & Scollie, 1999). In addition, the RECD is used to adjust the electroacoustic fitting so the final output in the real-ear will be correct for an individual child (Seewald et al, 1999). This use of the measurement is especially important when real-ear aided response measures are not possible.

b) Minimally, the fitting method employed to determine hearing instrument electroacoustic characteristics should be audibility based (i.e., the goal would be

to provide audibility of an appropriate amplified long-term amplified speech spectrum). When nonlinear circuitry is considered, the prescriptive formula should take into account speech audibility at different input levels (eg., NAL-NL1 or DSL [i/o], Byrne, et al., 2001; Cornelisse, et al., 1995). That is, the primary goal is the audibility of speech regardless of input level or vocal effort.

c) Target values for gain and output are determined through the use of a prescriptive formula (evidence-based independent or evidence-based device-related) by using hearing sensitivity data and the RECD.

d) Although none of the threshold-based selection procedures are guaranteed to ensure that a child will not experience loudness discomfort or that output levels are safe, the use of a systematic objective approach that incorporates age-dependent variables into the computations is preferred. Frequency-specific loudness discomfort levels should be obtained when children are old enough to provide reliable responses (Gagné, Seewald, Zelisko & Hudson 1991a, 1991b).

e) The audiologist may consider the need to reduce gain recommended by a particular fitting strategy if binaural summation is not considered in the fitting strategy and the fitting is binaural. Currently, there are not data that clearly illustrate binaural summation experienced through hearing aids in the soundfield. Scollie et al (2000) reported no binaural summation as measured through preferred listening levels in children who were using hearing aids. In addition, the desired frequency/gain response and output limiting may need to be modified from the prescription if the hearing loss is primarily conductive or if there is a conductive component.

f) The electroacoustic parameters of the hearing instrument are pre-set so as to achieve the targeted response. Coupler measurement allows for pre-setting the hearing aids prior to fitting them to the child. Pre-setting in the pediatric population is especially important because the child may not provide reliable feedback for fine-tuning.

g) Further electroacoustic measurement after the desired output (gain) has been set should include verification of low distortion at varying inputs at user prescribed settings.

6. Verification

a) The electroacoustic performance of the instrument should be matched to the prescribed 2 cm3 coupler target values for gain and output limiting where the 2 cm3 coupler values have been derived using an individualized real ear to 2 cm3 coupler transform (e.g., the RECD).
b) Aided soundfield threshold measurements may be useful for the evaluation of audibility of soft sounds but they are not recommended and should not be used

for verifying electroacoustic characteristics of hearing instruments in infants and children for several reasons:

1) prolonged cooperation from the child is required
2) frequency resolution is poor
3) test-retest reliability is frequently poor
(Seewald, Moodie, Sinclair & Cornelisse 1996)
4) misleading information may be obtained in cases of severe to profound hearing loss, minimal or mild loss, or when non-linear signal processing, digital noise reduction, or automatic feedback reduction circuitry is used

c) Probe microphone measurements employing an insertion gain protocol are not the preferred procedure for verifying electroacoustic characteristics of hearing instruments in infants and children for several reasons:

1) targets are provided outside of any relevant context (i.e., threshold) and consequently are not directly audibility based
2) targets assume an average adult REUG

d) Output characteristics should be verified using a probe microphone approach that is referenced to ear canal SPL. Determination of audibility at several input levels is the ideal method of verification. This requires the placement of a probe microphone and hearing aid in the child's ear while sound is presented through a loudspeaker at several intensity levels (e.g., soft, moderate, loud). The resulting real ear aided response (REAR) can be compared to thresholds and UCLs (measured or age-appropriate estimation) converted to ear canal SPL. This provides a direct measurement of the predicted levels of amplified speech. The clinician must select signals for this type of testing that ensure accurate electroacoustic verification. As hearing aid technology changes (processing various input signals in different ways), the clinician must update his/her knowledge as to the appropriate signal to use for testing and may need to update his/her equipment with newly developed signals (Scollie & Seewald, 2001). All air conduction hearing aid technology can be measured electroacoustically in some appropriate manner.

e) If probe-microphone measures of real-ear hearing aid performance are not possible, hearing aid performance can be predicted accurately in the real ear by applying age appropriate average RECD values to the measured 2-cc coupler electroacoustic results (Seewald et al., 1999).

f) As audibility is one of the main goals of the pediatric fitting, the Situational Hearing-Aid Response Profile (SHARP, Stelmachowicz, Lewis, Kalberer, Creutz, 1994) may be used to verify predicted audibility in a variety of settings that cannot easily be measured in a clinical setting. Measured hearing aid characteristics (test chamber or probe-microphone data) are entered into this software program and the audibility for twelve different listening situations (e.g.,

cradle position, hip position, 1 meter, 4 meters, child's own voice, etc.) is evaluated. Estimated performance displayed on a hearing aid manufacturer screen during programming without the direct measurement of a probe microphone is an estimate of performance based on a variety of estimations associated with the individual's ear and hearing aid. These data cannot be relied on for verification purposes.

Note: In the various procedures described under Verification, a signal must be presented to the hearing aid whether it is being tested with a microphone in the test chamber or with a probe microphone in the real ear. The test signal should adequately represent the frequency, intensity, and temporal aspects of speech. Recent investigations have illustrated that various advanced signal processing interacts with the test signal and that the most accurate representation of the hearing aid's response will be through the use of a speech-like signal or by turning off signal processing during test that attempts to reduce output that it considers noise (Scollie & Seewald, 2002; Scollie, Steinberg, Seewald, 2002).

7) Hearing Instrument Orientation and Training

Orientation and training should include family members, caregivers, and the child. This information also must be communicated to the child's educators through interactions with the educational audiologist, deaf and hard-of-hearing specialist, or other qualified personnel. Orientation and training should be discussed, demonstrated, and sent home in a written or video format. Orientation and training may take place over several appointments based on the family's and child's ability to perform tasks.

Orientation and training will include:

a) care of the hearing aids, including cleaning and moisture concerns
b) suggested wearing schedule and retention
c) insertion
d) removal
e) overnight storage (including the mechanism for turning off the hearing aids)
f) insertion and removal of the batteries
g) battery life, storage, disposal, toxicity
h) basic troubleshooting (batteries, feedback, plugged earmold and/or receiver)
i) telephone coupling and use
j) assistive device coupling and use
k) moisture solutions (e.g., dehumidifying systems and covers)
l) tools for maintenance and care (e.g., battery tester, listening stethoscope, earmold air blower)
m) issues of retention/compliance/loss (including spare hearing aids and any loaner program)
n) recommended follow-up appointments to monitor use and effectiveness

8. Validation

a) Validation of aided auditory function is a demonstration of the benefits and limitations of aided hearing abilities and begins immediately after the fitting and verification of amplification. Validation is an ongoing process designed to ensure that the child is receiving optimal speech input from others and that his or her own speech is adequately perceived (Pediatric Working Group, 1996). In addition to ongoing monitoring of the amplification device, objective measures of aided performance in controlled clinical environments and in real world settings may be included in the validation process. Functional assessment tools assist in the monitoring process by evaluating behaviors as they occur in real-world settings. These tools are typically questionnaires designed for administration to parents and teachers or assessments that can be conducted in the child's school environment.

b) Aided speech perception measures
Aided speech perception tasks including, but not limited to, the Low-Verbal Early Speech Perception Task and the Early Speech Perception Task (Moog & Geers, 1990), Phonetically Balanced Kindergarten List (PBK, Haskin, 1949), Northwestern University's Children's Perception of Speech Test (NUCHIPS, Katz & Elliott, 1978), Pediatric Speech Intelligibility Test (PSI, Jerger, Lewis, Hawkins, & Jerger, 1980) may be used in the validation process.

c) Functional Assessment Tools
   1) Tasks conducted in the classroom setting or questionnaires completed by educators such as the Functional Listening Evaluation (Johnson & Von Almen, 1997), the SIFTER (Anderson, 1989), the Pre-school SIFTER (Anderson & Matkin, 1996) may be used for functional assessment, and the Listening Inventory for Education (LIFE) questionnaire (Anderson & Smaldino, 1996).
   2) Questionnaires completed by parents or caregivers such as the Children's Home Inventory of Listening Difficulties (CHILD) (Anderson & Smaldino, 2000), the Family Expectation Worksheet (Palmer & Mormer, 1999), the Early Listening Function (ELF) (Anderson, 2002), the Meaningful Auditory Integration Scale (MAIS) (Robbins, Renshaw, & Berry, 1991), the Infant-Toddler MAIS (IT-MAIS) (Zimmerman, Osberger, Robbins, 1998), the Meaningful Use of Speech Scale (MUSS) (Robbins, Svirsky, Osberger & Pisoni, 1998), and the Functional Auditory Performance Indicators (FAPI) (Stredler-Brown, Johnson, 2001) also may provide useful validation mechanisms.

The tools listed above should be helpful in planning for the individual child. The majority of these tools, however, do not have published psychometric data at this time. With these data, it would not be appropriate to use these tools to document significant change in performance.

9. Follow-up and Referral

Parents and other family members or individuals who will assist in caring for the amplification system should receive orientation, training, and ongoing support and appropriate referral as needed from the audiologist. The audiologist is a key professional who can provide education or refer families to those who can educate them about hearing loss.

Fitting of personal amplification in an infant or young child is an on-going process. Minimally, an audiologist should see the child every three months during the first two years of using amplification and every 4-6 months after that time (The Pediatric Working Group, 1996). Follow-up appointments should include:

a) Behavioral audiometric evaluations
b) Current assessment of communication abilities, needs, and demands
c) Adjustment of the amplification system based on updated audiometric information and communication demands
d) Periodic electroacoustic evaluations
e) Listening checks
f) Earmold fit check
g) Periodic probe-microphone measurements (at a minimum, following replacement of earmolds)
h) Periodic functional measures to document development of auditory skills (see Section 8: Validation)
i) Long-term follow-up including academic progress (tools may include the Meadow-Kendall Social-Emotional Scales (Meadow-Orlans, 1983).
On-going auditory habilitation should be provided as part of a team of professionals including, but not limited to, audiologists, early interventionists, deaf and hard-of-hearing specialists, speech-language pathologists, classroom teachers, pediatricians, or pediatric otologists with the primary focus to support families in the development of the communication abilities of their children.
j) The prudent audiologist will want to help the parent or guardian make sure that the hearing aids are covered for loss, damage, and repair at all times. For a variety of reasons, the pediatric population has a fairly high rate of loss, damage, and repair. Coverage may be available through the hearing instrument company, a hearing aid insurance company, or a homeowner's policy.

References

American National Standards Institute. Specification of hearing aid characteristics. ANSI S3.22-1996, New York.

Anderson KL. (1989). Screening Instrument for Targeting Educational Risk (SIFTER).Tampa, FL, Educational Audiology Association.

Anderson KL & Matkin ND. (1996). Screening Instrument for Targeting Educational Risk in Preschool Children (age 3-kindergarten) (Preschool SIFTER). Tampa, FL, Educational Audiology Association.

Anderson KL , Smaldino J. (2000). Children's Home Inventory of Listening Difficulties (CHILD). Educational Audiology Review, 17(3), Suppl.

Anderson, KL, Smaldino, J. (1996). Listening inventory for Education (LIFE), an efficacy tool. Educational Audiology Association, [on-line].. Available: www.edaud.org.

Anderson, KL. (2002). Early Listening Function (ELF). Educational Audiology Association, [on-line]. Available: www.edaud.org.

Bess FH, Dodd-Murphy J, Parker RA. (1998). Children with minimal sensorineural hearing loss: Prevalence, educational performance, and functional status. Ear and Hearing, 19(5): 339-354.

Bess FH, Tharpe AM. (1984). Unilateral hearing impairment in children. Pediatrics, 74: 206-216.

Bess, F., Tharpe, A.(1988). Performance and management of children with unilateral sensorineural hearing loss. In Barajas JJ and Borg E (Eds), Overview and Evaluation of the Hearing-Impaired Child – Imaging and Audiology. Scandanavian Audiology Supplement, 30, 75-79.

Boothroyd, A. (1993). Recovery of speech perception performance after prolonged auditory deprivation: Case Study. Journal of the American Academy of Audiology, 4, 331-337.

Byrne D, Dillon H, Ching T, Katsch R, Keidser G. (2001). NAL-NL1 prodedure for fitting nonlinear hearing aids: Characteristics and comparisons with other procedures. J Amer Acad Audiol. 12, 37-51.

Ching, T., Dillon, H., Byrne, D. (1998). Speech recognition of hearing-impaired listeners: Predictions from audibility and the limited role of high-frequency amplification. Journal of the Acoustical Society of America, 103, 1128-1140.

Ching, T., Dillon, H., Katsch, R. (2001). Do children require more high-frequency audibility than adults with similar hearing losses? A sound foundation through early amplification: Proceedings of the Second International Conference. Phonak, Inc.: Chicago, IL. 141-152.

Cornelisse, L., Seewald, R., Jamieson, D. (1995). The input/output formula: A theoretical approach to the fitting of personal amplification devices. Journal of the Acoustical Society of America, 97(3), 1854-1864.

Gagné, J.P., Seewald, R.C., Zelisko, D.L., Hudson, S.P. (1991a). Procedure for defining the auditory area of hearing impaired adolescents with severe/profound hearing loss I: Detection thresholds.l Journal of Speech Langauge Pathology and Audiology, 15(3):13-20.

Gagné, J.P., Seewald, R.C., Zelisko, D.L., Hudson, S.P. (1991b). Procedure for defining the auditory area of hearing impaired adolescents with severe/profound hearing loss II: Loudness discomfort levels. Journal of Speech Language Pathology and Audiology, 15(4): 27-32.

Gravel, J., Fausel, N., Liskow, C., Chobot, J. (1999). Children's speech recognition in noise using omnidirectional and dual-microphone hearing aid technology. Ear and Hearing, 20(1), 1-11.

Haskin, H.A. (1949). A phonetically balanced test of speech discrimination for children. Master's thesis, Northwestern University: Evanston, Illinois.

Hattori, H. (1993). Ear dominance for nonsense-syllable recognition ability in sensorineural hearing-impaired children: Monaural versus Binaural amplification. Journal of the Academy of Audiology, 4, 319-330.

Hawkins, D., Naidoo, S. (1993). Comparison of sound quality with asymmetrical peak clipping and output limiting compression. American Journal of Audiology, 4, 221-228.

Hawkins, D., Yacullo, W. (1984). Signal-to-noise ratio advantage of binaural hearing aids and directional microphones under different levels of reverberation. Journal of Speech and Hearing Disorders, 49(3), 278-286.

Hogan, C., Turner, C. (1998). High frequency audibility: Benefits for hearing-impaired listeners. Journal of the Acoustical Society of America, 104(1), 432-441.

Jenstad, L, Seewald, R., Cornelisse, L., Shantz, J. (1999). Comparison of linear gain and WDRC hearing aid circuits: Aided speech perception measures. Ear and Hearing, 20, 117-126.

Jenstad, L., Pumford, J., Seewald, R., Cornelisse, L. (2000). Comparison of linear gain and WDRC hearing aid circuits II: Aided loudness measures. Ear and Hearing, 21, 32-44.

Jerger, S., Lewis, S., Hawkins, J., and Jerger, J. (1980). Pediatric speech intelligibility test: I. Generation of Test materials. International Journal of Pediatric Otorhinolaryngology 2: 217-230.

Johnson, CD and Von Almen, P (1997). Functional listening evaluation. In Johnson, C.D., Benson, P.V., & Seaton, J.B. Educational audiology handbook. San Diego: Singular Publishing Group, Inc., pp. 336-339.

Johnson, W., Killion, M. (1994). Amplification: Is class D better than class B? American Journal of Audiology, 3, 11-13.

Joint Audiology Committee. (2000). Audiology Clinical Practice Algorithms and Statements, Audiology Today, Special Issue, August 2000.

Katz, D.R., and Elliott, L.L. (1978). Development of a new children's speech discrimination test. Paper presented at the convention of the American speech and Hearing Association, November 18-21, Chicago.

Kenworthy, O.T. Klee, T., Tharpe, A.M. (1990). Speech recognition ability of children with unilateral sensorineural hearing loss as a function of amplification, speech stimuli, and listening condition. Ear and Hearing, 11, 4.

Killion, M., Wilber, L., Gudmundsen, G. (1988). Zwislocki was right… a potential solution to the "hollow voice" problem. Hearing Instruments, 39(1), 14-18.

Kortekaas, R., Stelmachowicz, P. (2000). Bandwidth effects on children's perception of the inflectional morpheme (s): Acoustical measurements, auditory detection, and clarity rating. Journal of Speech, Language, and Hearing Research, 42, 645-660.

Kuk, F., Kollofski, C., Brown, S., Melim, A., Rosenthal, A. (1999). Use of a digital hearing aid with directional microphones in school-aged children. Journal of the American Academy of Audiology, 10(10): 535-548.

Matkin, N.D. (1996). The potential benefits of amplification for young children with normal hearing, in: FH Bess, JS Gravel & AM Tharpe (eds) Amplification for Children with Auditory Deficits. Nashville: Bill Wilkerson Center Press.

Meadow-Orlans KP (1983). Meadow-Kendall Social/Emotional assessment Inventory (SEAI) for Deaf and Hearing-Impaired Students. Gallaudet University.

Moog, J.S., Geers, A.E. (1990). Early speech perception test for profoundly hearing-impaired children. St. Louis: Central Institute for the Deaf.

Moore, B. (2001). Dead regions in the cochlea: implications for the choice of high-frequency amplification. A sound foundation through early amplification: Proceedings of the Second International Conference. Phonak, Inc.: Chicago, IL., 153-166.

Palmer, C. (2001). The impact of hearing loss and hearing aid experience on sound quality judgments. Seminars in Hearing, 22, 125-138.

Palmer, C., Killion, M., Wilber, L., Ballad, W. (1995). Comparison of two hearing aid receiver-amplifier combinations using sound quality judgments. Ear and Hearing, 16(6), 587-598.

Palmer, C., Mormer, E. (1999). Goals and expectations of the hearing aid fitting. Trends in Amplification, 4 (2), 61-71.

Preves, D., Newton, J. (1989). The headroom problem and hearing aid performance. The Hearing Journal, 42, 19-26.

Ricketts, T., Henry, P. (2002). Low-frequency gain compression in directional hearing aids. American Journal of Audiology, 11 (1), 1-13.

Ricketts, T., Mueller, G. (2000). Predicting directional hearing aid benefit for individual listeners. Journal of the American Academy of Audiology, 11(10), 561-569.

Robbins AM, Renshaw JJ, & Berry SW. Evaluating meaningful auditory integration in profoundly hearing impaired children. Am J Otol 12:144-150, 1991.

Robbins AM, Svirsky, Osberger, & Pisoni (1998). Beyond the audiogram: The role of functional assessments. In: Bess FH, ed. Children with Hearing Impairment: Contemporary Trends. Nashville: Bill Wilkerson Center Press, 1998, pp 105-124.

Scollie, S., Seewald, R., Cornelisse, L., Jenstad, L. (1998). Validity and repeatability of level dependent HL to SPL transforms. Ear and Hearing, 19, 407-413.

Scollie, S., Seewald, R. (2001). Electroacoustic verification measures with modern hearing instrument technology. A sound foundation through early amplification: Proceedings of the Second International Conferences. Phonak, Inc.: Chicago, IL. 121-137.

Scollie, S., Seewald, R. (2002). Hearing aid fitting and verification procedures for children. In Katz, J. (5th Edition). Handbook of Clinical Audiology, Lippincott/Williams and Wilkins: New York. 695-696.

Scollie, S., Seewald, R. (2002). Evaluation of electroacoustic test signals. 1 – Comparison with amplified speech. Ear and Hearing, 23(5), 477-487.

Scollie, S., Steinberg, M.J., Seewald, R. (2002).. Evaluation of electroacoustic test signals. 2 – Development and cross validation of correction factors. Ear and Hearing, 23(5), 488-498.

Seewald, R., Scollie, S. (1999). Infants are not average adults: Implications for Audiometric Testing. Hearing Journal, 52(10), 64-72.

Seewald, R.C., Moodie, K.S., Sinclair, S.T., Cornelisse, L.E. (1996). Traditional and theoretical approaches to selecting amplification for infants and children. In F.H.Bess, J.A.Gravel, and A.M. Tharpe (Eds). Amplification for Children with Auditory Deficits. Vanderbilt University Press.

Seewald, R., Moodie, S., Sinclair, R., Scollie, S. (2000). Predictive validity of a procedure for pediatric hearing instrument fitting. American Journal of Audiology, 8(2), 143-152.

Skinner, M., Miller, J. (1983). Amplification bandwidth and intelligibility of speech in quiet and noise for listeners with sensorineural hearing loss. Audiology, 22, 253-279.

Stedler-Brown A, Johnson C. DeConde, (2001). Functional Auditory Performance Indicators: an integrated approach to auditory development. [on line] , Colorado Department of Education, Special Education Services Unit. Available: www.cde.state.co.us/cdesped/specificdisability-hearing.htm

Stelmachowicz, P. (2001). The importance of high-frequency amplification for young children. A sound foundation through early amplification: Proceedings of the Second International Conference. Phonak, Inc.: Chicago, IL., 167-175.

Stelmachowicz, P., Lewis, D., Kalberer, A., Creutz, T. (1994). Situational Hearing-Aid Response Profiel (SHARP, Version 2.0). User's Manual. Boys Town National Research Hospital, 555 North 30th Street, Omaha, Nebraska 68131.

Stelmachowicz, P., Pittman, A., Hoover, B., Lewis, D. (2001). Effect of stimulus bandwidth on the perception of /s/ in normal – and hearing-impaired children and adults. Journal of the Acoustical Society of America, 110, 2183-2190.

Teder, H. (1993). Compression in the time domain. American Journal of Audiology, 2(2), 41-46.

The Pediatric Working Group. (1996). Amplification for infants and children with hearing loss, Nashville, TN: Bill Wilkerson Press.

Turner, C., Cummings, K. (1999). Speech audibility for listeners with high-frequency hearing loss. American Journal of Audiology, 8, 47-56.

Valente, M. (1982a). Binaural amplification: Part 1. Audiol: J for Continuing Education 7(6).

Valente, M. (1982b). Binaural amplification: Part 2. Audiol: J for Continuing Education 7(6).

Zimmerman, S, Osberger, MJ, & Robbins, AM (1998). Infant-Toddler: Meaningful Auditory Integration Scale (IT-MAIS). In: W. Estabrooks (ed). Cochlear Implants for Kids. Washington: AG Bell Association for the Deaf.

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