

American Academy of Audiology  
Clinical Practice Guidelines

**Pediatric Amplification**

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# American Academy of Audiology Clinical Practice Guidelines

## Pediatric Amplification

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## 1. INTRODUCTION/DEVELOPMENT PROCESS

This document was prepared by the American Academy of Audiology Task Force on Pediatric Amplification. The specific goal of this document is to provide a set of statements, recommendations, and strategies for best practices specific to the application of amplification as part of a comprehensive treatment plan for the audiologic management of children with hearing loss. Specific statements and recommendations were made by initially reviewing the existing scientific evidence published in peer-reviewed and non-peer-reviewed journals. When direct evidence was not available, both indirect evidence (often evidence from adults), and consensus practice were considered in making recommendations. In some cases recommendations are based on acoustic or physical facts where an empirical evidence base is not necessary and would not be expected (known as First Principles). This guideline addresses the technical aspects of hearing aid selection, fitting, verification, and outcomes assessments. This guideline does not address treatment solely with cochlear implants, but does touch on cochlear implants used in conjunction with a hearing aid on the contralateral ear.

This guideline is not intended to serve as a standard to dictate precisely how hearing aids should be selected, verified, or validated. This guideline is meant to provide the evidence base from which the clinician can make individualized decisions for each patient. In addition, the guideline can help inform physicians, reimbursement agencies, government agencies, the hearing health-care industry, patients, families, and caregivers about what research evidence demonstrates are current best practices related to amplification. Finally, although this guideline addresses the technical aspects involved in the fitting of hearing aids, the audiologist is reminded that the process of fitting hearing aids is an ongoing one requiring joint participation of the audiologist, patient, and family/caregivers. As indicated, input should also be sought from the Early Intervention provider, the classroom teacher, and other pertinent stakeholders.

The process of developing this guideline was evidence-based when possible. Evidence-based practice integrates clinical expertise with the best available clinical evidence derived from systematic research. Where evidence is ambiguous or conflicting, or where scientific data are lacking, the clinical expertise of the task force was used to guide the development of consensus-based recommendations.

The previous document, *Pediatric Amplification Guidelines* (2003), comprised eight areas of focus: 1) audiologic candidacy criteria, 2) principles underlying effective amplification, 3) signal processing and features, 4) fitting/verification, 5) other verification tools, 6) outcomes assessment, 7) management, follow-up and referrals, and 8) use of hearing aids with other hearing technologies. In the literature search for the present document, task force members first sought to identify studies at the top of the hierarchy of study types (see Table 1). Once definitive clinical studies that provided valid relevant information were identified, the search stopped. The search was extended to studies/reports of lower quality only if there were no higher quality studies. Traditionally, the highest levels of evidence include systematic reviews/meta-analyses of randomized controlled trials and randomized controlled trials (Levels 1 and 2). The crossover design is a valuable variation of the randomized controlled trial. Subjects are first identified and then randomized into treatment groups with each group receiving a different treatment. After experiencing the treatment for a specified period, each subject “crosses over” and receives the other treatment for a period of time. In a crossover design, all subjects produce data from all of the treatments. In this manner, there are no issues related to group equivalence when the treatments are compared. For these reasons, studies implementing crossover designs were labeled as Level 2 in this document.

**Table 1. Explanation of levels of evidence and grades of recommendation**

<b>Levels of Evidence</b>
1. Systematic reviews and meta-analyses of randomized controlled trials
2. Randomized controlled trials
3. Non-randomized intervention studies
4. Descriptive studies (cross-sectional surveys, cohort studies, case-control designs)
5. Case studies
6. Expert opinion

  

<b>Grades of Recommendation</b>
A. Consistent level 1 or 2 studies
B. Consistent level 3 or 4 studies or extrapolations from level 1 or 2 studies
C. Level 5 studies or extrapolations from level 3 and 4 studies
D. Level 6 evidence or troubling inconsistencies or inconclusive studies at any level

Adapted from Cox, R. (2005). Evidence-based practice in provision of amplification. *Journal of the American Academy of Audiology*, 16(7),419-438.

In addition to grading the evidence and assigning it a level (see Table 1), it was determined if the evidence was Efficacy (EF) or Effectiveness (EV). EF is evidence measured under “laboratory or ideal” conditions and EV is evidence measured in the “real world.” Each section provides relevant background, a list of recommendations, and a table with each recommendation, the source (citation), level of evidence, grade, indication of support of efficacy and/or effectiveness, and indication of whether the recommendation is being extrapolated from adult data (see Table 2 for an example table).

In some cases recommendations are based on acoustic or physical facts where an empirical evidence base is not necessary and would not be expected. In cases where the recommendation is based on a physical or acoustic fact (a First Principle), either “acoustic fact” or “physical fact” is listed under “Source” in the evidence tables (for an example of the format of an evidence table, see Table 2).

**Table 2. Sample Recommendations and Summary of Evidence table**

<b>Rec</b>	<b>Evidence</b>	<b>Source</b>	<b>Level</b>	<b>Grade</b>	<b>EF/EV</b>	<b>Adult</b>

Please note: the recommendations made in this document will not be referenced in the traditional manner but all references will be provided in full at the end of the section, following the Summary of Evidence table. Additionally, a complete reference list is available at the end of the guideline.

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## 2. OVERVIEW OF PEDIATRIC AMPLIFICATION

The purpose of amplification is to provide to an infant or child with impaired hearing the opportunity to have access to as much of the auditory environment, and in particular speech, as feasible. Provision of appropriate amplified auditory input to the child with hearing loss maximizes the opportunities for the child to develop age-appropriate receptive and expressive oral communication, language development, literacy skills, and psychosocial skills.

The primary goal of amplification is to provide, to the degree possible given the hearing loss and limitations of hearing aid amplification, audibility across the long-term average speech spectrum (LTASS), without delivering any signal that is of an intensity that would be either uncomfortable or unsafe. Goals of amplification also include minimal distortion, appropriate signal-processing strategies for the listener, features that maximize audibility of the desired signal and, insofar as possible, reduction of undesired signals (noise), flexibility and ease of connection to external devices, and physical comfort such that consistent, daily use is possible.

Audiologists are the single professional knowledgeable and competent to manage all aspects of amplification. Successful amplification can only be based on complete and accurate diagnosis/measurement of hearing sensitivity. The audiologic diagnosis must be conducted using best practices, employing developmentally-appropriate tests, and result in reliable and valid findings. At a minimum, thresholds by air- and bone-conduction for a low frequency (e.g., 500 Hz) and a high frequency (e.g., 2000 Hz) stimulus must be obtained in each ear separately. These thresholds can be obtained via behavioral or electrophysiologic measures, preferably both. The Joint Committee on Infant Hearing (2007) recommends at least one ABR evaluation for all children under the age of 3 who are diagnosed as having a hearing loss. The hearing aid fitting process should not be delayed because full diagnostic data are not available.

An audiologist serves as case manager in the audiologic diagnostic and treatment processes. While the diagnostic audiologist may not manage the case of a patient who proceeds to hearing aids, the audiologist responsible for the treatment of the patient will serve as the case manager. Working collaboratively with the early intervention team, which may include teachers of the hard of hearing and deaf, speech-language pathologists, psychologists, physicians, occupational and/or physical therapists, and geneticists, the audiologist ensures that the child and family are connected with appropriate services. All care is provided in a family-centered environment and in a manner that is culturally and linguistically appropriate. Materials must be provided in the family's preferred language and mode of communication, at a reading-level that is appropriate to the reader. In some cases, information also should be presented in video-format (e.g., those with a primary communication mode of American Sign Language) or pictorial rather than written format for families with low reading levels.

Amplification is provided based on the contemporary knowledge of a child's hearing loss and communication needs. Regular, reliable and valid measures of a child's progress in meeting early intervention goals (e.g., speech, language, auditory skills, and psychosocial development) are necessary as part of the intervention process to ensure that amplification outcomes are being achieved. Should the goals of early intervention change, or should change in hearing sensitivity occur, amplification needs and goals may change accordingly. Should alternative amplification system(s) be initiated (e.g., cochlear implant), hearing aid amplification may need to be modified. Without regular assessment of (unaided) hearing, as well as general outcomes, opportunities for modification to best meet the child's needs may be missed.

Children have unique characteristics that require special consideration for assessment and treatment. Some of these characteristics are discussed below, with emphasis added on key points.

Children and adults have different patterns of hearing thresholds, due at least in part to the different causes of hearing

loss in children versus adults. Specifically, the incidence of asymmetrical, progressive, and varied configurations of audiometric thresholds across frequencies is higher in the pediatric population. This creates specific needs for device flexibility in frequency shaping and in the fitting range, as well as in device matching between ears.

Similarly, childhood hearing impairment is more likely to be comorbid with other health conditions. Special fitting considerations and different physical features or signal processing may be required.

Infants may be assessed using electrophysiologic estimates of hearing sensitivity. Some techniques for performing and interpreting these measures require corrections or adjustments to the resulting values prior to their use in conjunction with hearing aid prescription formulae.

Children's relatively smaller but growing external ears create a unique assessment and fitting challenge that requires individualized measures of ear canal status, made repeatedly throughout the child's life and incorporated each time within the prescription and hearing aid fitting. The physical size and shape of the instrument directly affects the comfort, fit, and retention of the device. The acoustic coupling of the device to the ear is affected by the current size of the child's ear (and other factors). In many cases, the best measure to make and use to account for the child's ear is the real-ear to coupler difference (RECD). However, the RECD measure is transducer-specific and does not capture sound incoming through a vent or slit-leak. Therefore, transition to real-ear measurement ("in situ") or other evidence-based protocol selection is required.

Children have different requirements of their hearing. Several related but unique adult-child differences emerge from the literature:

- Children are learning language, and do not have the capacity to "fill in the blanks" for sounds not audible in the way that adult listeners have.
- Children spend most of their time listening to the speech of other children and women, which has greater high frequency content than that of adult males. This places greater importance on providing audibility for the high-frequency cues of speech when providing hearing aids for the pediatric population.
- Children who use hearing aids must develop the ability to use information acquired while hearing amplified, processed sound. Children fit with hearing aids that fail to render audible the full set of speech cues are at risk of deficits in speech production and/or learning.
- Children have more demanding listening requirements than adults for understanding speech, particularly when the listening situation is difficult (low in level, noisy, and/or reverberant). Enhancement of audibility is required to support better speech understanding, either through increased level, increased signal-to-noise ratio, or improvement of the listening environment. Prescriptive targets for children may specify greater outputs in quiet environments than for adults. Strategies for hearing aid use in the classroom should include strategies or devices to address the effects of distance and reverberation.
- Children's hearing aid use is typically mediated by a caregiver, at least through the early years of life. For this reason, issues of device use and monitoring, and caregiver training, are unique challenges in the pediatric population.

Hearing aid manufacturers typically offer custom hearing aid prescriptions that have been developed by and for the proprietary use of the hearing aid company. Such prescriptions are not standardized nor are they typically subjected to external scrutiny, and are typically developed for use in the adult population. Use of independently validated pediatric-focused prescriptive targets, as well as normative data, and fitting methods is always recommended.

Evidence-based independent prescriptive methods are specific computations designed for use with the pediatric population. Validation studies indicate high levels of speech recognition in controlled and real world environments when hearing aids are fit using both prescriptive targets and individualized fittings methods that employ verification of audibility (typically completed through the use of specific real-ear probe microphone measures) and level-dependent signal processing.

In creating this document, the task force was fully aware of the difficulty of providing a guideline for the pediatric population which is defined as birth to 18 years of age. One might likely suggest providing four guidelines. This could be segmented into Infants (birth to two), Pre-school (2.5 to 5), School Age (5.5 to 12), and Young adult/Adult (12.5 to 18). Age groups could be conceived through auditory development, auditory demands, and/or the child's developmental stage in terms of accessing technology. The current guideline does not separate the age groups but is cognizant that in many cases the evidence base is coming from children 5 years or older. In the future, it may be prudent to produce individual guidelines or to incorporate the evidence base in a way that illustrates the population under study by age range. As with any guideline, it is incumbent on the practicing clinician to interpret the evidence base for the individual patient.

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### 3. AUDIOLOGIC CANDIDACY CRITERIA

#### Objective

The purpose of providing amplification for children is to minimize the negative impacts of hearing loss on communication development and academic achievement. Amplification systems should, therefore, be considered for any type or degree of hearing loss that could possibly interfere with normal developmental processes, including minimal/mild or unilateral hearing loss or Auditory Neuropathy Spectrum Disorder. Children with severe or profound hearing loss who may not achieve sufficient levels of aided audibility and speech discrimination ability with hearing aids to support the development of auditory skills and speech understanding should be referred for a cochlear implant evaluation, assuming parent/caregiver preference.

#### Recommendations for Determining Candidacy

1. Children with aidable unilateral hearing loss should be considered candidates for amplification in the impaired ear due to evidence for potential developmental and academic delays. Children with unilateral hearing loss are at greater risk than children with normal hearing for speech and language delays and academic difficulties. For children with severe or profound unilateral hearing losses and normal hearing in the other ear, Contralateral Routing of Signal (CROS) or bone conduction devices may be considered depending on the child's age and ability to control their environment. Currently there is a paucity of data available to inform these decisions.
2. Children with minimal and mild hearing loss are at high risk for experiencing academic difficulty and may be considered candidates for amplification systems.
3. Children with Auditory Neuropathy Spectrum Disorder (ANSD) should have a trial with amplification as soon as it can be established that hearing sensitivity is sufficiently poor that speech at conversational levels will not be easily audible. Because neither the auditory brainstem response (ABR) in children with ANSD, nor the presence or absence of otoacoustic emissions provides a valid estimate of behavior threshold, amplification should only be provided based on behavioral observations (by the clinician and by parents) until reliable behavioral thresholds can be established. Children with ANSD may or may not demonstrate improvements in speech understanding with the provision of amplification. Based on the potential for improved speech recognition and the difficulty in predicting hearing aid benefit from audiological characteristics, a trial with appropriately fit amplification for children with ANSD is recommended prior to candidacy evaluation for cochlear implantation. Until hearing thresholds can reliably be established, careful observation of the responsiveness of the child to sounds while wearing hearing aids is essential, with adjustments to the degree of amplification as necessary. Alternatively, information about the audibility of speech with and without hearing aids can be obtained from assessment of cortical responses evoked by speech sounds.
4. Children with permanent conductive hearing loss should be fit with air conduction hearing aids when anatomically possible (sufficient external ear and canal anatomy to support the coupling of an earmold and retention of the device), or bone conduction hearing aids if anatomy is insufficient for coupling (atresia, chronically draining ears, or other significant anatomical malformations).
5. All potential candidates for a cochlear implant should receive a trial with hearing aid amplification prior to implantation, to determine if sufficient benefit accrues from appropriately-fit hearing aids. A finding of "No Response" by auditory brainstem response (ABR) does not exclude a child from hearing aid candidacy, as residual hearing may exist at intensity levels greater than those capable of being elicited using standard ABR. The threshold levels used

to prescribe amplification for a no response ABR should be equal to the lowest-intensity stimulus level where no response is observed for each frequency tested, except in the case of children with ANSD where the absence of an ABR does not carry any implications about hearing thresholds.

## Summary of Evidence for Audiological Candidacy

Rec	Evidence	Source	Level	Grade	EF/EV	Adult
1	Children with aidable unilateral hearing loss should be considered candidates for amplification due to evidence for potential developmental and academic delays.	1	4	C	EF	
2		4	C	EF		
10		4	C	EF		
11		4	C	EV		
2	Children with mild hearing loss should be considered candidates for amplification.	2	4	C	EF	
3		4	C	EF		
4		4	C	EV		
5		4	C	EV		
2	Children with minimal hearing loss should be considered for remote microphone technology to improve signal to noise ratio.	Acoustic fact				
3	Children with auditory neuropathy spectrum disorder (ANSD) should have a trial with amplification unless it can be established that the child is responsive to speech sounds at conversational levels without hearing aids. The hearing aid prescription should be altered as further information about hearing thresholds becomes available.	6	3	B	EF	
7		3	B	EF		
8		3	B	EF		
4	Children with permanent conductive hearing loss should be fit with air conduction hearing aids when anatomically possible, and bone conduction hearing aids if anatomy is insufficient for coupling.	Physical fact			EF/EV	
5	Children with profound hearing loss by auditory brainstem response should not be excluded from receiving hearing aids prior to evaluation for a cochlear implant.	9	5	D	EF	

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## 4. PRINCIPLES UNDERLYING EFFECTIVE AMPLIFICATION

### Objective

Many decisions must be made prior to selecting amplification for a child. These decisions are based on individualized 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. The overarching goal is to match the technology/features of the amplification system to the needs and abilities of the pediatric patient. Many of these decisions must be revisited on an ongoing basis as the child matures.

### 4.1 Routing of the Signal

#### Background

The routing of the signal may include air conduction, bone conduction, electrical stimulation or some combination of these methods. In addition, the signal may be routed to one ear, both ears or in the case of bone conduction to both cochleae with the better cochlea utilizing the signal. When the signal is delivered to both ears, the signal processing may be independent (bilateral) or coordinated at some level as in the case of hearing aids that compare

settings in a wireless manner to ensure similar microphone setting, volume control settings, etc. between ears. Bilateral amplification is recommended for most patients with hearing loss in both ears regardless of symmetry. Monaural fittings may be warranted based on specific patient needs or in cases of asymmetry with potential binaural interference.

### **Air conduction versus Bone Conduction Transmission**

Typically, air conduction hearing aids are the standard treatment for sensorineural hearing loss and conductive hearing loss assuming the hearing aids can be coupled to the ear (e.g., no malformation of the outer ear or recurrent drainage). If coupling is not possible, a bone conduction hearing aid may be more appropriate. A bone conduction hearing aid may be worn as a completely external device with a band creating the pressure needed to transmit the vibrated signal or it may be coupled with an implanted abutment (i.e., osseointegrated device). The implantation and support of a bone anchored hearing aid requires collaboration between the audiologist and otolaryngologist/otologist. The FDA has approved the use of the bone anchored hearing aids for children five years and older, though bone conducted amplification is often used without implantation via a soft headband in children younger than 5.

### **Electrical Stimulation**

Individuals with severe to profound sensorineural hearing loss in both ears are candidates for cochlear implants. A cochlear implant provides tonotopic electrical stimulation to the auditory nerve. Some children may use a hearing aid in one ear and a cochlear implant in the other (bi-modal). Hybrid amplification devices are a combination of hearing aids and cochlear implants and provide acoustic amplification to the low frequencies and electrical stimulation to the higher frequencies. These devices are not currently approved for use in the United States, nor with children.

### **Unilateral Hearing Loss**

Contralateral routing of the signal (CROS) and Bilateral routing of the signal (BICROS) fittings are specially designed for patients having either unilateral hearing loss or bilateral asymmetrical hearing loss where one ear is unaidable, respectively. Currently, wired and wireless configurations are available. For the child with unilateral deafness, an FM system with the wireless remote microphone receiver portion coupled to the open, good ear may be preferable in classroom situations to the CROS arrangement to give the benefit of increased signal to noise ratio, a benefit in a noisy classroom. The transcranial CROS is an option for individuals who have no auditory response in one ear. In this configuration, a powerful hearing aid is fit to the non-responsive ear so interaural attenuation is overcome and sound is perceived by the functioning cochlea. This is not a common fitting for children and again, an appropriately fit assistive listening device may be a better communication solution in the classroom. The osseointegrated hearing device described earlier also can be used as an implanted transcranial CROS; evidence supporting benefit of this arrangement in children is limited.

If the unilateral hearing loss is aidable then a monaural fitting would be considered.

### **Recommendations for Selecting Routing of the Signal**

1. Bilateral amplification is recommended unless contraindicated.
2. Sound transmission is chosen based on type and severity of the hearing loss and physical features of the outer ear.
3. Bi-modal sound transmission (CI on one side and hearing aid on the other) is recommended for children unilaterally implanted unless contraindicated.

4. For a child with unilateral deafness, an FM system with the wireless remote microphone receiver coupled to the open, good ear may be preferable to a CROS configuration in classroom situations.
5. Use of a bone conducted signal may be an effective means of amplification for children with permanent bilateral conductive hearing loss.
6. Use of a bone conducted signal may be considered an option with children who have unilateral hearing loss.

### Summary of Evidence for Selecting Routing of the Signal

Rec	Evidence	Source	Level	Grade	EF/EV	Adult
1	Bilateral amplification is routinely recommended unless contraindicated.	2	3	B	EV	
		3	3	B	EV	
2	Sound transmission is chosen based on type and severity of the hearing loss and physical features of the outer ear.	acoustic and physical fact			EF/EV	
3	Bi-Modal sound transmission is recommended for children unilaterally implanted unless contraindicated.	1	3	B	EV	
		11	3	B	EV	
4	For a child with unilateral deafness, an FM system with the wireless remote microphone receiver coupled to the open, good ear may be preferable to a CROS configuration in classroom situations.	4	3	B	EV	
5	Use of bone conducted signal for children with permanent bilateral conductive hearing loss	5	4	C	EF	
		6	4	C	EF	
		9	4	C	EF	
		10	4	C	EV	
6	Use of bone conducted signal for children with UHL	7	3	B	EF	
		8	3	B	EV	
7	Use of a hearing aid when unilateral loss is aidable.	12	3	B	EF	
		13	3	B	EF	

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## 4.2 Selection of Hearing Aid Style

### Objective

The choice of hearing aid style should be made based on factors such as gain and output requirements, bandwidth, ear canal size and shape, expected changes in concha and ear canal size, skin sensitivity, and need for specific features (e.g., directional microphone, telecoil, direct auditory input, built-in FM receiver), comfort, occlusion considerations, and cosmetic concerns. For the pediatric patient, expected changes in ear size generally promotes the behind-the-ear (BTE) style as the preferred choice due to the need to replace only the relatively inexpensive ear mold as the child grows. The outer ear may continue to grow well into puberty, thus dictating the BTE style. In

addition, for many pediatric patients, features such as directional microphones, telecoils, direct auditory input, and built-in wireless (e.g. FM) receivers are desirable and are found on the BTE style of hearing aid.

### BTE Terminology

The slim tube is a method of coupling a BTE or mini-BTE to the ear. This tubing is often designed to end in a small dome that can either leave the ear canal open or mostly close it, but can end with a more traditional, closed mold. A second style of mini-BTE places the receiver in the ear canal, rather than in the hearing aid case. This style of hearing aid is referred to in different ways, depending on the manufacturer’s preferred nomenclature. It may be referred to as a Receiver in the Canal (RIC), Receiver in the Ear (RITE) or Canal Receiver Technology (CRT). The Hearing Industries Association (HIA) uses the term RIC and that term will be used in this document. The Receiver in the Aid (RITA) is the traditional configuration and can be coupled to standard or slim tubing and to an open or closed ear mold. The RIC removes the receiver from the BTE case with a wire running down the slim tube connecting the BTE circuitry to the receiver that is now in the ear canal. This style allows for a smaller BTE case while still having the amplification power of a more traditional BTE. It also allows room for a larger battery in a smaller case. The potential disadvantage is consistent with the disadvantages of the ITE, ITC, and CIC styles in that the receiver is now more exposed to moisture, heat, and cerumen in the ear canal. Many of the mini-BTE options do not offer telecoils, coupling for FM input or locking battery doors.

### Recommendations for Hearing Aid Style

1. BTEs are the style of choice while the child’s ear is still growing.
2. BTEs may provide needed features for the pediatric patient.
3. Standard BTEs may provide appropriate coupling to a variety of assistive listening devices that may assist in educational and social settings. Not all RIC or mini-BTEs will have the ability to couple to assistive devices.
4. Tubing size, occlusion, and receiver placement are individual choices based on patient communication needs, ear canal dimensions, hearing loss severity and configuration, and patient preferences.

### Summary of Evidence for selecting hearing aid style

Rec	Evidence	Source	Level	Grade	EF/EV	Adult
1	BTEs are the style of choice while the child’s ear is still growing.	physical fact			EF/EV	
2	BTEs may provide needed features for the pediatric patient.	acoustic fact			EF/EV	
3	BTEs will provide appropriate coupling to a variety of assistive listening devices that may assist in educational and social settings.	acoustic fact			EF/EV	
4	Tubing size, occlusion, and receiver placement are individual choices based on patient communication needs, ear canal dimensions, hearing loss severity and configuration, and patient preferences.	acoustic and physical fact			EF/EV	

## 4.3 Adequacy of Earmold

### Background

If a behind-the-ear hearing aid is chosen for the pediatric patient, an earmold to couple the device to the ear canal must be selected. The audiologist should consider the style, material, color, length, and frequency of remakes for the earmold. The need for well-fitting earmolds has increased with the advent of wide dynamic range, wideband hearing aids, but has also decreased with the increase in effectiveness and use of feedback management algorithms. The audiologist is able to make a wide range of sounds audible in an automatic way by using amplitude compression circuitry with no volume control. The use of automatic technology without the need for a volume control forces the audiologist to be more proactive about regular earmold changes. Feedback suppression may alleviate this problem temporarily while the new earmold is ordered. Clinicians should use caution with feedback suppression and remember that it may alter the frequency and gain characteristics of the response. As such, the feedback suppression features, if used, should be active during the verification process. See section 6.1 later in the guideline for more discussion on this topic. However, feedback management should not be used to extend the life of poorly fitting earmolds, as significant changes in the acoustics of the earmold coupling are likely to occur as the child outgrows their earmolds. 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. Venting earmolds for children should be approached cautiously. Venting alters the hearing aid's frequency response, and certain placements of venting (i.e. vents that intersect the sound bore) may create problems in sound channel tubing retention and reduce the bandwidth of the hearing aid response. For many infants and young children, internal venting will not be possible due to the small size of the earmold and the gain and output requirements that may produce feedback if venting is used. External venting (removal of material from the outside surface of the mold) is usually possible from a space perspective, but the potential difficulty with feedback oscillation remains. In order to maintain appropriate gain, manage the small size of the earmold, and minimize the occlusion effect (OE), it may be necessary to 1) separate the microphone and location of the acoustic output of the hearing aid by using a behind-the-ear style and potentially coupling this with a remote microphone (hearing assistance technology), 2) use feedback management algorithms, 3) reduce occlusion by extending the canal of the earmold to the bony portion of the ear canal (deep fit). The long earmold canal has the added benefit of reducing the volume of the ear canal between the end of the earmold and the tympanic membrane, thereby increasing the sound pressure level that is achieved in the ear canal (without increasing the gain or battery drain of the hearing aid). While increased gain can be a benefit, it is essential to account for this change in sound pressure level by measuring the child's real-ear-to-coupler difference (RECD) and applying this correction during the verification process so as to ensure that the output is appropriately limited for the individual child. In addition, the output achieved in the ear canal will change as the child grows and each time a new earmold is fit, requiring repeated real-ear and RECD measures with each new earmold.

The sound channel consists of the ear hook and tube that leads through the earmold and sends sound into the ear canal. Just as a horn (increased diameter at the end of the 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 ear canal is so small that the sound channel decreases in diameter from the tubing to the sound bore. It is essential that the end of the sound channel be checked visually for crimping. It may be necessary to not "tube through" an infant's earmold to avoid crimping or unnecessarily restricting the diameter of the sound channel. An electroacoustic measure that includes the earmold or probe microphone measures with the earmold connected to the hearing aid will reveal any roll off in high frequency response.

Manufacturers generally send adult size ear hooks unless otherwise instructed. A pediatric ear hook can be crucial for ensuring retention of the hearing aid. BTE tubing systems (comprising the receiver tube, earhook, and earmold tubing) 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) ear hook will smooth the frequency response. Changing from an adult to pediatric earhook will alter the hearing aid response. Any changes to the sound channel require that new real-ear measures are made.

Earmolds and tubing can separate from the hearing aid and can be swallowed. The integrity of the connection between the earmold, tubing, ear hook, and hearing aid should be checked at the child's regular visits to the clinic.

### Recommendations for adequacy of earmold

1. Be proactive regarding earmold replacement due to the child's growth.
2. Use automatic feedback suppression in order to resolve feedback issues, either temporarily while awaiting new earmolds or permanently if needed to achieve the prescribed gains. Use feedback cancellation (which does not reduce the gain below the value that applies in the absence of feedback oscillation) in preference to feedback management systems that operate by reducing gain in one or more frequency regions, at one or more input levels, until feedback oscillation ceases.
3. Approach venting cautiously in pediatric earmolds because of space limitations.
4. For infants, the only way to fully eliminate feedback may be to use an offsite/remote microphone. Caution must be used when considering this as a full time option because the child may not hear his/her own babbling/speech sounds if the microphone is not near the child's mouth.
5. Provide a long, but comfortable earmold canal length to reduce the occlusion effect and to provide increased output in the ear canal due to decreased volume between the earmold and eardrum.
6. Guard against reverse horns created by crimping the end of the sound channel in small earmolds.
7. Use pediatric ear hooks to promote retention of BTEs.
8. Use filtered ear hooks to ensure a smooth frequency response.

### Summary of evidence related to selection of the ear mold

Rec	Evidence	Source	Level	Grade	EF/EV	Adult
1	Be proactive regarding earmold replacement due to the child's growth	physical fact			EF/EV	
2	Consider automatic feedback suppression in order to resolve feedback issues temporarily while awaiting new earmolds	acoustic fact			EF/EV	
3	Approach venting cautiously in pediatric earmolds because of space limitations	acoustic fact			EF/EV	

4	Consider off site microphones to eliminate feedback for infants. Children will not be able to monitor speech/babble in this configuration.	acoustic fact			EF/EV	
5	In adults, some negative effects of occlusion can be reduced with a longer ear canal portion to the earmold	acoustic fact			EF/EV	
5	Increased output can be achieved with a longer ear canal portion to the earmold	acoustic fact			EF/EV	
6	Avoid reverse horns and monitor for crimping at the earmold sound bore	acoustic fact			EF/EV	
7	Pediatric ear hooks may help with retention	physical fact			EF/EV	
8	Filtered ear hooks will provide a smooth frequency response.	acoustic fact			EF/EV	

## 4.4 Safety Considerations

### Background

Several categories of potential hearing aid-related adverse effects emerged from the literature. These may be related to either physical or acoustic features of the hearing aid.

**Battery door:** Specific risks of battery ingestion include toxicity and asphyxiation. Children under age 6 are at greater risk for battery ingestion. The audiologist should recommend tamper-resistant battery doors for younger children and parents should be supplied with the poison control center number should a battery be ingested. Battery recycling or other safe disposal of hearing aid batteries is recommended.

**Volume Control:** A volume control may come in the form of a wheel, toggle, touch sensor or button. 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). Adjustment of a volume control can provide a short-term solution to feedback caused by poorly fitting earmolds, but reductions in volume to minimize feedback will reduce the overall audibility of the hearing aid fitting. 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 a parent/caregiver). Most hearing aids are equipped with the ability to activate and de-activate certain features on the hearing aid including the volume control and memory button. The audiologist may want to de-activate the volume control for a young child but have the option to activate the feature as the child matures over the life of the hearing aid.

**Overamplification:** The gain-frequency response and maximum output of the hearing aid should be set according to published, independent prescriptive fitting formulae in conjunction with the measured real-ear-to-coupler difference (see section 6.1 for additional details regarding the RECD). Gain settings significantly in excess of prescriptive targets may result in further damage to residual hearing. Excessive output may be especially damaging for children with severe to profound hearing loss (i.e., thresholds of approximately 90 dB HL or higher). If overamplification is suspected, monitoring of Temporary Threshold Shift (TTS) by measuring audiometric thresholds before and after a day of device use is recommended. Threshold-shift in excess of 5 dB may indicate overamplification. Exceeding the safety limit is unlikely when hearing aids are fit to independent prescriptive formulae, when nonlinear signal processing is used, and when the user has hearing levels below the severe to profound range (lower gains are necessary). Prescriptive targets have a degree of caution built in to the suggested

outputs so fitting a hearing aid with less than the prescribed maximum output is not advised since this may lead to reduced headroom, thereby increasing the compression ratio needed.

**Parental anxiety, training, and resulting device use:** Effective counseling and coaching are required to ensure that parents are prepared, technically and emotionally, to provide hearing aid use support for infants and young children. Support in various forms (e.g. device retention, coaching/counseling regarding developmentally appropriate expectations) is required to work with families to promote appropriate use across environments and developmental stages. Parents of children with hearing loss may exhibit concerns at the time of hearing aid fitting regarding hearing aid maintenance, appearance and potential benefit. Parents may experience anxiety resulting from the hearing aid fitting, apart from anxiety specific to the identification of hearing loss. Consistency of device use varies across families, environments, degree of hearing loss and developmental stages.

**Nonfunctioning hearing aids:** An overall loss (i.e., the combination of loss of open ear canal resonance and earmold attenuation) of a nonfunctioning hearing aid can range from 25-30 dB. This is equivalent to that of noise attenuation devices, and represents a significant loss of sound compared to either the unaided or aided listening condition. Regular checks by caregivers are needed to ensure that hearing aids are functional.

Care should be taken to ensure that parents are skilled at monitoring device function and troubleshooting. The specific mechanism for achieving these goals will vary with the child's caregivers, environments, and abilities over time. Caregiver listening checks without further support (via written materials) may be insufficient to ensure daily functioning of hearing aids. Parents may require/prefer written materials to supplement in-person training regarding daily check procedures.

**Ear impressions and contact dermatitis:** Ear impression taking carries several risks, including impaction of cerumen, injury to the ear canal or tympanic membrane, injection of material into the middle ear space, or contact dermatitis arising from the type of ear impression material used. In addition, some earmold or earshell materials carry risk of contact dermatitis. Case history of prior skin reactions should precede ear impression taking to avoid re-exposure to allergenic materials. Selection of materials with lower allergenic properties can assist in avoiding most, but not all, skin reactions. Patients with pre-existing ear abnormalities are at greater risk of complications arising from ear impression procedures. Contact dermatitis is also a risk of ear impression taking and/or earpiece use. Risk is dependent on both material type and patient susceptibility.

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.

## **Recommendations for safety considerations**

1. Utilize tamper resistant battery doors to decrease the likelihood of battery ingestion.
2. De-activate or lock volume controls, or utilize wide dynamic range compression thereby eliminating the need for volume control manipulation for audibility and comfort.
3. Use a validated, pediatric-focused prescriptive formula and account for the real-ear to coupler difference (RECD) when prescribing gain or output for a child in order to avoid overamplification.
4. Monitor temporary threshold shift (TTS) if overamplification is suspected.
5. Attempt to reduce parental/caregiver anxiety through counseling and instruction.

6. Provide parents/caregivers with tools and instructions to ensure functioning hearing aids.
7. Identify prior skin reactions in order to minimize incidence of contact dermatitis with earmold impression and/or earmolds.

### Summary of evidence for safety considerations

Rec	Evidence	Source	Level	Grade	EF/EV	Adult
1	Use tamper resistant battery doors	physical fact			EF/EV	
2	De-activate or lock volume control	acoustic fact			EF/EV	
3	Use an independent prescriptive formula that accounts for the real-ear to coupler difference (RECD) when prescribing gain or output for a child in order to avoid overamplification.	1 2 3 4 5 6 7 8 9	4 4 4 4 5 3 3 3 4	D D D D D B B B C	EF EF EV EV EV EF EF EV EV	
4	Monitor TTS if overamplification is suspected.	7	3	B	EV	
5	Attempt to reduce parental/caregiver anxiety through counseling and instruction.	10 11 12	4 4 4	C C C	EV EV EV	
6	Provide parents/caregivers with tools and instructions to ensure functioning hearing aids.	13 14	4 6	C D	EV EV	
7	Identify prior skin reactions in order to minimize incidence of contact dermatitis with earmold impression and/or earmolds.	15	3	B	EV	

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## 5. SIGNAL PROCESSING AND FEATURES

### Objective

For the child with hearing loss the audiologist often begins a rehabilitative treatment plan with the selection of appropriate amplification. This process includes matching appropriate signal processing features to the child's listening needs. Defining the listening needs of any child will be based on the degree, configuration, and type of hearing impairment as

well as consideration of environmental, familial and economic factors. The choice of appropriately validated features and related signal processing for each individual is paramount.

## Fundamental Requirements for Hearing Aid Audio Signal Processing

1. The system should avoid unnecessary distortion.
2. The system should allow sufficient frequency shaping to meet the prescriptive requirements of the hearing loss configuration.
3. The system should employ amplitude compression that offers the flexibility to restore audibility for low level inputs while maintaining comfort for high level inputs.
4. Output limiting must be sufficient to avoid exposure to loud sounds while minimizing electroacoustic distortion.

## Recommendations for Hearing Aid Audio Signal Processing

Until sufficient data are available to exclude the following processing techniques each should be considered viable and preferable for the pediatric fitting of hearing aids.

1. **Compression in the dynamic range:** The system should employ an amplitude compression strategy. As with the adult patient, the prescription of amplification gain for the pediatric patient should ensure that a range of input levels are compressed sufficiently to accommodate sensitivity to loud sounds while restoring low level speech audibility. In meeting these requirements, selection of compression characteristics should also minimize alteration of speech cues. The generation of pediatric- focused target gains should be done with an independent prescriptive procedure that accommodates the considerations discussed above.
2. **Software bands:** A minimum of four to seven software adjustment bands (i.e., handles) should be selected for the digitally programmed hearing aid. It is expected that this will allow for sufficient frequency shaping to meet the needs of most audiometric configurations. There should not be a disadvantage to increasing the number of bands beyond seven. The system also should allow sufficient flexibility to accommodate the child's growth, any progression or fluctuation in hearing thresholds, and any related changes to frequency shaping (e.g., larger ear canals or increased vent diameter may require an increase in prescribed gains).
3. **Compression channels:** Multi-channel compression should be selected for the management of frequency specific audibility. Increasing the number of channels beyond one may increase audibility (as shown by predictive models of audibility), particularly for sloping audiograms, but may also reduce the discrimination of sounds on the basis of their spectral shapes. The disadvantages associated with a high number of channels increase with the size of the compression ratio used.
4. **Output limiting:** Output limiting will constrain the maximum output of any hearing aid. This constraint will assist in avoidance of discomfort, as well as avoidance of possible sound-induced threshold-shift, for loud inputs. Compression output limiting will provide superior sound quality as compared to hearing aids that limit maximum output through peak clipping. Inaccurate prescription of output limiting (unnecessarily low or high) has been shown to decrease speech recognition in adults.
5. **Expansion at low input levels:** Expansion at low input levels is expected to improve comfort by reducing audibility of low level environmental sounds. There is evidence to suggest that expansion also will decrease audibility of low

level speech if the expansion threshold is set too high. Thus the prescription of expansion in children should be done with the understanding that prioritizing comfort in quiet environments also may have a negative effect on audibility of low level speech inputs.

6. **Extending high-frequency bandwidth:** Extended high-frequency bandwidth (up to 9000 Hz) will improve audibility for sounds such as /s/ that represent an essential cue for the recognition of plural or possessive statements in the English language. The clinician should not conclude that a lack of increased performance from high-frequency amplification implies a decrease in performance.
7. **Techniques for frequency lowering:** Individual techniques for frequency lowering have markedly different effects on the amplified speech spectrum; the clinical implications of these differences are not understood. There is evidence to suggest that frequency lowering may improve detection and recognition of high-frequency consonants for children with high-frequency hearing loss ranging from moderate to profound. There also are data that suggest acclimatization to frequency lowered amplification may increase both acceptance of and performance with a given frequency lowering technique. Fitting of any frequency lowering algorithm should be accompanied by behavioral validation. Frequency lowering should be treated as a form of distortion purposefully introduced to the amplified pathway. Fine tuning and the accompanying verification and outcome assessment should have the goal of providing the least possible effect (distortion) that allows access to high frequency sound. Frequency lowering should not be prescribed until electroacoustic verification has revealed that high-frequency speech audibility cannot be restored through conventional means.
8. **Feedback suppression:** It is an acoustic fact that feedback suppression will decrease the occurrence of feedback oscillation (i.e., whistling). The reduction of feedback will allow for larger vents and increase the time period between earmold remakes. All verification should be performed after the activation of any modern feedback suppression algorithm as it is a common process for manufacturers to limit accessible gains during the initialization process of the feedback suppression algorithm.
9. **Directional microphones:** Full-time directional processing is not recommended. This feature may be recommended for children, although there are common listening environments in which directional technology is not desirable. The directional mode may reduce audibility of off-axis talkers, limiting overhearing and related incidental learning. Small but significant additional directional benefits may be associated with adaptive directional microphone technology and no significant negative consequences are associated with adaptive directional processing in adult listeners.
10. Hearing aids that automatically switch between directional and omnidirectional modes depending on which mode produces the signal with the greater apparent signal-to-noise ratio should be considered. However, it is the responsibility of the audiologist to understand the switching parameters of the automatic program as well as the acoustic conditions of the educational setting in order to establish appropriate expectations for any automatic switching behavior.
11. In some cases full-time omnidirectional mode may be preferred to an automatic directional mode. All children with hearing loss should be considered candidates for FM use. When appropriately prescribed, FM systems will provide improvements in signal-to-noise ratio that are similar or superior to directional microphones.
12. **Digital noise reduction:** Adult listeners are expected to experience reduced annoyance and increased acceptance of background noise when listening with digital noise reduction. On average, digital noise reduction is not expected to negatively impact speech recognition ability in children. The prescription of digital noise reduction

should be done with the understanding that different implementations of this technology vary in their electroacoustic behavior and that prioritizing comfort or the acceptance of background noise may negatively impact speech audibility.

## Summary of Evidence for Signal Processing

Rec	Evidence	Source	Level	Grade	EF/EV	Adult
1	Independent prescriptive formulas provide a starting point for target gains at multiple input levels.	8	3	C	EV	Adult
		11	4	C	EF	Adult
		27	2	A	EF	
1	Compression applied across the dynamic range may improve low level speech audibility while maintaining comfort	9	3	B	EF	
		10	3	C	EF	
2	Seven bands will provide sufficient frequency shaping to address most audiometric configurations.	1	3	C	EF	Adult
3	Speech recognition differences have been associated with increased number of compression channels, but some experiments have shown no increase in speech recognition with increased number of compression channels.	33	4	C	EF	
4	Compression output limiting maintains sound quality when compared to peak clipping.	37	4	C	EF	Adult
5	Expansion may reduce low level speech audibility and recognition of low level speech segments.	4	3	B	EF	Adult
		32	3	C	EF	Adult
6	Audibility of extended high-frequencies positively impacts recognition of high-frequency consonants for children.	12	3	B	EF	
		28	3	B	EF	
		29	3	B	EF	
7	Frequency lowering is a form of acoustic distortion that, when properly prescribed, may provide access to high frequency cues for the child with unaidable high frequency hearing loss.	2	3	B	EF	Adult
		6	3	B	EF	
		23	3	C	EF	
		34	2	A	EF	
		35	3	B	EV	

7	Frequency lowering improves consonant recognition for some listeners with hearing loss ranging from moderate to profound for children and adults.	2	3	B	EF	Adult
		6	3	B	EF	
		23	3	C	EF	
		35	3	B	EV	
7	Consonant recognition ability with frequency lowering will improve with listening experience and training both in children and adults	2	3	B	EF	Adult
		23	3	C	EF	
		35	3	B	EV	
8	Gain limitations introduced during the initialization process of feedback suppression algorithms may limit the fitting range of that device	Acoustic fact			EF/EV	
9	Directional hearing aids provide speech understanding in noise benefits to adults in many noisy environments. However, decrements also may be present in some environments.	3	1	A	EF	Adult
		13	3	C	EF	Adult
		15	3	C	EF	Adult
		22	3	C	EF	Adult
		23	4	C	EF	Adult
		24	3	C	EF	Adult
		31	3	C	EV	Adult
		36	3	C	EF	Adult
		Acoustic fact				
9	Children as young as 4 months of age can and do orient their heads towards sound sources of interest in home environments 40% of the time. Children in the study were not wearing amplification.	5	4	B	EV	
9	Children in simulated school environments exhibit significant directional benefit when they are facing the signal of interest. Measured and self-reported increased difficulties with speech recognition can occur in the directional mode when the signal of interest is behind the listener. These difficulties are of considerable concern if the hearing aid does not automatically switch to omnidirectional processing in such situations, given evidence that children can and do learn through overhearing speech that is presented off-axis, even when distracted.	7	3	B	EV	
		20	3	B	EF	
		21	3	B	EF	

9	For children, speech recognition benefits experienced with directional microphones are generally smaller than those observed when using FM technology.	19	3	B	EF	
9	Small but significant additional directional benefits may be associated with adaptive directional microphone technology and to date; no significant negative consequences are associated with adaptive directional processing in adult listeners.	13	3	C	EF	Adult
10	Adults experience reduced annoyance and listening effort when using digital noise reduction.	16	3	C	EF	Adult
		17	3	C	EF	Adult
		25	3	C	EV	Adult
		26	3	C	EF	Adult
10	On average digital noise reduction does not negatively impact speech recognition ability.	18	3	B	EF	Adult
		30	3	B	EF	

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## 6. FITTING/VERIFICATION

### 6.1 Electroacoustic Hearing Aid Fitting

#### Objective

The objective of this segment of the fitting process is to assure that the fitting and verification procedure is viewed as a process rather than an event, which culminates in the optimal fitting for the child. Verification procedures also serve as a benchmark against which future hearing aid changes can be compared.

## Recommendations for Fitting/Verification

1. **Prescription methods:** Independent pediatric-focused and pediatric-validated prescriptive targets, normative data, and fitting methods that take into account the unique developmental and auditory needs of children should be used for pediatric hearing aid verification instead of manufacturer's proprietary prescriptive approaches. Pediatric and adult populations differ significantly in areas that directly affect the prescription of appropriate hearing aid gain, output, and signal processing. Hearing aid manufacturers typically offer custom hearing aid prescriptions that have been developed for proprietary use with their hearing aids. Such prescriptions are not standardized or subjected to external scrutiny and are typically developed for use in the adult population. As such, their incorporation of important pediatric considerations is both unknown and unlikely. Significant variance in gain and output among manufacturer-driven fittings has been demonstrated, even for the same audiogram. Validation studies indicate high levels of speech recognition in controlled and real world environments when hearing aids are fit using prescriptive targets generated by independently developed formulae such as the Desired Sensation Level (DSL) or National Acoustics Laboratories (NAL) prescriptions and when the individualized fitting is verified through real-ear, probe microphone measurements.
2. **Verification methods:** The response of the hearing aid should be measured for a variety of input levels to estimate the audibility of speech and ensure that the maximum output does not exceed prescribed levels.

For children, there are two options for hearing aid verification:

1. Real-ear aided response (REAR) probe microphone measurements – The output of the hearing aid is measured in the child's ear (in situ) using a probe microphone. This option is a better choice for highly vented fittings and for children with earmold tubing that is longer than 35 mm than simulated real-ear aided response measurements. The response of the hearing aid should be measured for a variety of input levels, minimally for average level speech input and maximum power output of the hearing aid.
2. Simulated real-ear aided response measurements in the coupler using measured or age-appropriate real-ear to coupler difference (RECD). The output of the hearing aid is measured in a 2cc coupler. The RECD is used to convert coupler measures to estimates of SPL in the child's ear and to accurately display target fitting data against which to compare the estimated output in the ear canal. This option is a better choice for unvented fittings, fittings that cannot be verified on the ear without feedback, and for infants and young children who cannot sit for real-ear measurements.

Clinicians should consider multiple factors when determining which method will be used for verification. Simulated real-ear aided measurements using a previously measured RECD to estimate the output in the individual child's ear canal may be more practical than direct real-ear aided response measurements with children because it is a single measurement, requires less cooperative time from the child, and is not affected by head movement. Because the signals used to verify maximum output are loud and may startle young children, simulated, coupler measurements of maximum output using RECD may be preferable over real-ear maximum output measurements. Correct use of the RECD in clinical practice relies upon appropriate clinical decision-making, and consideration of five evidence-based points:

1. The RECD is measurable in most cases, as long as it is attempted routinely. One common practice is to measure the RECD for at least one ear, and apply it to the fitting of both ears each time new earmolds are obtained. An RECD from one ear may be a good predictor of the RECD in the other ear. If this is not possible on a case by case basis, age-appropriate predicted RECDs or recently measured RECDs from the same child may be used in lieu of newly measured RECDs. These substitute RECDs are likely less accurate

than a newly measured RECD. Audiologists who routinely measure the RECD report excessive cerumen or child non-compliance with probe insertion in less than 30% of cases.

2. The RECD differs by age (smaller ears generate larger RECDs). The RECD also differs based upon whether coupling to the ear is done with foam tips or earmolds during RECD measurement. Age- and coupling-appropriate predicted RECDs are available in the independently developed pediatric prescription software packages.
3. The RECD is used in two places during the hearing aid fitting process.
  - i. The RECD is used to convert thresholds to SPL or equivalent adult HL and therefore impact the calculated targets. This is done only for insert phone audiograms. These calculations are performed automatically by the independently developed pediatric prescription software packages.
  - ii. The RECD is used to convert measures or prescriptive targets to and from the coupler and the ear canal. These conversions also include other factors such as the microphone location effects and are included in the independently developed pediatric prescription software packages and real-ear measurement systems.
4. Use of the RECD measure in hearing aid fitting does not capture the acoustic effects of unamplified sound entering the ear canal via the vent.
5. The RECD is transducer-specific. Some differences in RECDs between the hearing aid, an insert phone, and system-specific RECD transducers have been noted. These differences are slight when the ear is very small and/or when filtered earhooks are incorporated into the fitting.

Taking all of these into consideration, verification systems employ prescriptions (DSL, NAL) that use the RECD when it is appropriate to do so, and automatically substitute age- and coupling-appropriate RECDs when necessary. Audiologists can support the accuracy of this process by providing measured RECDs when possible. Accurate incorporation of the RECD, when measured using the same transducer coupling ( earmold or foam tip) as is used in threshold measurement, is expected to produce a more accurate transformation from HL to SPL thresholds which in turn produces more accurate output targets which are based on the SPL thresholds. This allows for an accurate estimate of the hearing aid output that will be achieved at the individual child's eardrum. These transforms are automatically performed by pediatric hearing aid fitting software systems that employ either DSL v5 or NAL-NL1 or NL2.

3. **High Frequency Audibility:** Children use their hearing to develop communication and to support learning. Children typically spend most of their time listening to the speech of other children, and women, which has greater high-frequency content than speech of male talkers. The importance of providing audibility for the high frequency cues of speech is greater for the pediatric population. Children who use hearing aids require more high frequency audibility, and derive more benefit from audibility of high frequency cues when they are provided. Children who are fit with hearing aids that fail to render audible the full set of speech cues are at risk of deficits in speech production and/or learning. Children have different listening requirements for understanding speech, particularly when the listening situation is difficult (low in level, noisy, and/or reverberant).
4. **Verification of advanced features:** The impact of hearing aid signal processing and features such as directional microphones, digital noise reduction, feedback suppression and frequency lowering on audibility should be verified, if these features are determined to be appropriate. Hearing aid features such as directional

microphones, digital noise reduction, feedback suppression, and frequency-lowering signal processing are widely available and are being used with children. If utilized with children, the impact of these features on audibility of speech should be evaluated during the verification process. If the signal processing strategy includes automatic activation of any features, verification of feature activation should be included. Standardized methods for verification of these features have not been evaluated in peer-reviewed studies; however, recommendations are available.

5. **Verification Test Signal:** A standard real speech or a speech-like signal should be used when attempting verification of prescriptive methods for which the targets are based on speech inputs. That is, the preferred hearing aid verification method should include a test signal that produces an output similar to the output for a speech signal of the same input level. This would require that the test signal adequately represent the frequency, intensity, and temporal aspects of speech. The clinician must select signals ensuring accurate verification. Various features and signal processing (compression, noise reduction, feedback suppression, etc.) interact with the test signal and 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 tests that attempt to reduce output that it considers noise. While no direct evidence exists, it is an acoustic fact that disabling specific signal processing features may obscure potential interactions between signal processing schemes in the same hearing aid.

### Summary of Evidence for Fitting and Verification

Rec	Evidence	Source	Level	Grade	EF/EV	Adult
1	Independent prescriptive methods that take into account the unique developmental and auditory needs of children should be used for pediatric hearing aid verification instead of manufacturer’s proprietary prescriptive approaches.	2	4	B	EF	
		3	3	B	EF	
		4	2	A	EF/EV	
		5	2	A	EF/EV	
		11	4	B	EF	
		12	4	B	EV	
2	The response of the hearing aid should be measured for a variety of input levels to estimate the audibility of speech and ensure that the maximum output does not exceed prescribed levels. Real-ear output response measurements with the use of real-ear to coupler difference (RECD) to correct threshold and resulting target data in the child’s ear or 2 cc coupler measurements with measured or average RECD should be used for verification.	1	4	B	EF	
		2	4	B	EF	
		3	3	B	EF	
		6	4	B	EF	
		7	4	B	EF	
		8	4	B	EF	
		9	4	B	EF	
		16	3	B	EF	

3	Children who use hearing aids require more high frequency audibility, and derive more benefit from audibility of high frequency cues when they are provided. Children have different listening requirements for understanding speech, particularly when the listening situation is difficult (low in level, noisy, and/or reverberant).	10	4	B	EV	
		12	2	A	EV	
		13	4	B	EF	
		14	4	B	EF	
		15	4	B	EF	
4	The impact of hearing aid signal processing and features should be verified, if these features are determined to be appropriate for an individual child.	Acoustic fact			EF/EV	
5	Some signal processing can interact with the test signal. A test signal that is similar to speech in spectral and temporal content is preferable. Failing this, it is necessary to disable features that react differently to speech versus non-speech sounds, and the resulting measurement may then not be indicative of the hearing aid's performance when the features are re-enabled.	11	2	A	EF	

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## 6.2 Other verification tools

### Objective

Once primary hearing-aid verification has been completed, audiologists may perform additional verification procedures to quantify the acoustic characteristics of the device under listening conditions where the speech spectrum may differ from the standard signal used during assessment of gain and output.

#### 6.2.1 Recommendations for SII/SHARP

1. Estimates of speech audibility using the Speech Intelligibility Index (SII) can be used to evaluate speech audibility for hearing aid fittings once primary verification has been completed through the verification software or computer programs (i.e., Situational Hearing Aid Response Profile (SHARP)). The Speech Intelligibility Index (SII) is a standardized method of calculating the audibility of a speech signal that can be applied to hearing-aid verification results. Normative data for the expected SII have recently been published. Use of alternative speech spectra allows the audiologist to estimate speech audibility for situations, such as when a child is held on the parent or caregiver's hip or in the cradle position, where the level and spectrum of the speech signal may differ from that used during primary verification. The Situational Hearing Aid Response Profile (SHARP) is a computer program that allows calculation of Aided Audibility Index (AAI) using a variety of different speech spectra that estimate various listening conditions that may be encountered by children. These data may be helpful when

providing guidance to the speech-language pathologist about how well the child actually can monitor his/her vocalizations, discussing the impact of distance on audibility when discussing the need for a personal FM system in the classroom, etc. (Please note: An updated version of SHARP is expected to be released in 2013).

2. SII predictions will overestimate speech recognition scores for children, which should be taken into account when these estimates are used. While SII values can be used to predict speech recognition scores for adults with hearing loss no more than moderate at any frequency, SII values tend to overestimate speech recognition scores for children for any degree of hearing loss. While the SII can be used to compare the audibility of speech spectra across listening conditions, clinicians should recognize that the SII does not have similar predictive validity for speech recognition for children as it does for adults. The SII may be of limited value in cases where the speech spectrum is altered using frequency-lowering signal processing, because current SII methods do not account for changes in the distribution of the speech spectrum in the hearing-aid output. Research has not been conducted to predict the effects of frequency-lowering on SII estimates of audibility. Because of the different assumptions inherent to SHARP and Desired Sensation Level (DSL) prescriptive formula, such as the input speech level, differences may exist between the two programs in the predicted hearing aid output.

### Summary of Evidence for SII/SHARP

Rec	Evidence	Source	Level	Grade	EF/EV	Adult
1,2	SII can be used to quantify audibility for hearing-aid verification.	1 2 3	4 3 4	C B B	EF EF EF	Adult
1,2	SII-based predictions of audibility will overestimate speech recognition because as hearing loss increases, people of all ages are progressively less able to extract information from speech even when it is made audible and children, relative to adults, need a greater SII for the same speech intelligibility. These data should be applied with caution.	1 2	4 3	C B	EF EF	

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### 6.2.2 Cortical Auditory Evoked Potentials

#### Objective

Once primary hearing aid verification has been completed, audiologists may perform measurement of cortical

responses evoked by speech sounds to confirm that speech at conversational levels is invoking activity in the auditory cortex. These measurements are most valuable for children who are unable to give feedback as to the audibility of speech, either because they are too young for reliable behavioral testing or because of the presence of other disabilities that restrict communication ability. They are extremely valuable for children for whom there is any uncertainty over hearing thresholds, particularly those with auditory neuropathy spectrum disorder.

### **Recommendations for Cortical Auditory Evoked Potentials (CAEPs)**

CAEPs can provide information about the audibility of sounds (including speech sounds) and about the maturity of the auditory system. CAEPs in response to sounds presented in the sound field can be measured with and/or without amplification. Children should be in the same state that is desirable for behavioral testing: calm, awake and quiet. CAEPs provide three types of information:

1. **Presence or absence of a CAEP:** The presence of a CAEP in response to a speech sound indicates that the sound eliciting the CAEP is evoking activity in the auditory cortex. This provides confirmation that the hearing aid settings are sufficient to achieve audibility of speech at the sound level used for testing. The absence of a cortical response does not, however, necessarily indicate that a sound is inaudible, as different children require different sensation levels before cortical activity is sufficiently strong for it to be detected on the scalp. Determining presence or absence of a cortical response is facilitated by objective metrics. Some detection metrics have been shown to be at least as accurate as expert human clinicians in differentiating true cortical responses from random electrical activity on the scalp. Children for whom it is possible to detect CAEPs to a greater proportion of speech sounds presented are more likely to display greater functional hearing ability, so the presence of CAEPs is an indicator of the child's likely functional hearing ability. CAEPs do not, however, directly indicate the ability of a child to discriminate one sound from another. The absence of CAEPs unaided combined with the presence of CAEPs aided can be a valuable aid to counseling parents of babies whose hearing loss was detected at birth. This pattern of responses reinforces both the likely impact on the child if hearing aids are not worn, and provides reassurance that the child is detecting sounds when aided.
2. **Latency of a CAEP:** In children with normal hearing, the latency of the major positive peak in a CAEP decreases from around 250 ms at birth down to around 100 ms at age 5 years. Children deprived of audibility for the first months or years of life have CAEPs with a latency near that of a new-born baby when they first hear audible sounds. Provided sounds are made audible to them by age 3 years, the latency decreases to age-appropriate values over the ensuing months. The latency of a CAEP in a young child is therefore a marker of the extent to which the central auditory nervous system has been able to mature in response to auditory stimulation.
3. **Waveform morphology of a CAEP:** There is not yet sufficient knowledge available for any inference to be drawn when CAEPs are reliably present but display a waveform morphology markedly different from that expected for children of the age being testing.

## Summary of Evidence for CAEPs

Rec	Evidence	Source	Level	Grade	EF/EV	Adult
1	Some detection metrics are at least as accurate as expert human clinicians in differentiating true cortical responses from random electrical activity on the scalp.	1	4	B	EF	Adult
		2	4	B	EF	
2	CAEPs present for a greater proportion of speech sounds is associated with greater functional hearing ability and speech identification ability.	3	4	B	EF	
		4	4	B	EF	
3	The latency of a CAEP in a young child is a marker of the extent to which the central auditory nervous system has been able to mature as a result of receiving auditory stimulation.	5	4	C	EF	
		6	5	C	EF	
		7	5	C	EF	

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### 6.2.3 Aided Thresholds in the Sound Field

Recommendations for measurement of aided thresholds in the sound field

1. Measurement of aided sound field thresholds should not be used as a method of hearing aid verification. A commonly used measurement is the “aided audiogram” or “functional gain”. These two terms are not synonymous, but are related: “aided audiogram” simply implies that thresholds are determined in sound

field while the child is wearing their hearing aids. The aided audiogram may be obtained in each ear separately (with the contralateral ear masked if necessary), or obtained binaurally. “Functional gain” implies a comparison of the unaided thresholds (soundfield, either bilaterally or each ear separately with appropriate contralateral masking) with the aided thresholds in the comparable condition. This permits, theoretically, a determination of the insertion gain provided by the hearing aid(s). Both measures, while having appealing face validity, are fraught with potential error sources. These error sources are related to a) the patient; b) the interaction of the input stimulus with the hearing aid signal processing; c) the noise floor in the test booth, and d) the underlying principles involved in making assumptions based on these measures. Further, aided testing only samples hearing aid characteristics at widely-spaced intervals (octave/half-octave) and does not indicate the presence of peaks or troughs in the hearing aid response characteristics.

Specifically, test-retest reliability, commonly referred to as +/- 5 dB in the adult population, may be significantly greater in the pediatric patient. Depending on the child’s developmental level, interest in the test procedures, and other variables, test reliability may be large enough to obscure meaningful test results. Additionally, children are likely to move (both head position and possibly body position) during testing, which may result in significant increase or decrease in the test signal intensity at the ear or hearing aid microphone. The input stimulus, depending on its intensity, may interact with the hearing aid signal processing in a manner such as to over- or under-estimate the aided response. In children with normal or near-normal hearing in any portion of the frequency spectrum, but in particular the low-frequency region, the noise floor of the test booth may obscure (lessen) the apparent gain provided by the hearing aid in that frequency region.

2. In cases of bone conduction hearing aids, real-ear probe microphone measures cannot be conducted (when there is no acoustic signal in an ear canal), and the aided audiogram may be the most readily available verification option. In spite of its limitations, the aided audiogram can provide information, and in the case of bone conduction and frequency transposition/compression hearing aids, may be the most valid way to quantify the aided response with currently available technologies.

### Summary of Evidence for Functional Gain

Rec	Evidence	Source	Level	Grade	EF/EV	Adult
1	Functional gain audiograms should not be used as the primary method of hearing aid verification	1	4 Acoustic fact	B	EF	
2	Bone conduction does not allow for verification through probe microphone measurements	2	6 Acoustic fact	D	EF	

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## 7. OUTCOMES ASSESSMENT

### Objective

Outcomes assessment is an integral part of evidence-based clinical practice. This section identifies a range of qualitative and quantitative measures that are effective in documenting the successful use of and benefit from hearing aid use by children.

#### Recommendations for Outcomes Assessment

In order to validate benefits and/or assist with fine-tuning, every child should receive an outcomes assessment after amplification is provided. Whereas verification serves to ascertain that prescriptively appropriate amplification is provided, outcome assessment checks that amplification needs of individual children are met. Assessment tools available for children include subjective and objective measures as outlined in the following table (see Table 3). As new measures are continually being developed, this is not intended to be an exhaustive list. Even though laboratory-based assessments are useful, assessments of performance in real life are crucial to determining the effectiveness of amplification. Specific recommendations include the following.

1. Parental reports provide a reliable and sensitive method for evaluating alternative gain-frequency responses in hearing aids for children.
2. Outcome assessment should be carried out after introduction of new features in hearing aids. The need to evaluate amplification is supported by evidence showing that children's performance is affected by variations in gain-frequency response slope of >3 dB/octave; directionality of microphones; presence or absence of noise reduction; and applications of frequency compression or transposition in hearing aids.
3. For children older than about 6 years of age, paired-comparisons judgments may be used reliably to identify the optimal frequency response among a small set of alternatives. This assessment method may be more sensitive than speech perception testing, and is useful in identifying the way in which gain-frequency responses may be modified to meet individual needs.

**Table 3. Outcomes assessments for children**

	Clinic/Laboratory	Real World
Children <3 years old	Aided audiogram*	<p><i>Parents' Report:</i></p> <p>AL. Developmental Index of Audition and Listening (DIAL<sup>9</sup>)            AM. Functional Auditory Performance Indicators (FAPI<sup>10</sup>)            AN. Infant-Toddler Meaningful Auditory Integration Scale (IT-MAIS<sup>11</sup>)            AO. LittleEARS<sup>16,38</sup>            AP. Parents' Evaluation of Aural/oral Performance of Children (PEACH<sup>12</sup>)</p> <p><i>Teachers' Report:</i></p> <p>AQ. Teachers' Evaluation of Aural/oral Performance of Children (TEACH<sup>13</sup>)</p>

Children 3-6 years	<p><i>Speech perception:</i></p> <p>AR. Video Speech Pattern Contrast Test (VIDSPAC<sup>1</sup>)</p> <p>AS. Northwestern University-Children's Perception of Speech (NU-CHIPS<sup>2</sup>)</p> <p>AT. Word Identification by Picture Inventory (WIPI)</p> <p>AU. Phonetically Balanced Kindergarten (PBK<sup>3</sup>)</p> <p>AV. Aided Audiogram*</p> <p>AW. Ling 6 Sounds Test<sup>40</sup></p>	<p><i>Parents' report:</i></p> <p>AX. Auditory Behavior in Everyday Life (ABEL<sup>14</sup>)</p> <p>AY. Children's Home Inventory of Listening Difficulties (CHILD<sup>15</sup>)</p> <p>AZ. Meaningful Auditory Integration Scale (MAIS<sup>17</sup>)</p> <p>BA. Meaningful Use of Speech Scale (MUSS<sup>18</sup>)</p> <p>BB. Parents' Evaluation of Aural/oral Performance of Children (PEACH<sup>12</sup>)</p> <p><i>Teachers' report:</i></p> <p>BC. Screening Instrument For Targeting Educational Risk (Preschool SIFTER<sup>19</sup>)</p> <p>BD. Teachers' Evaluation of Aural/oral Performance of Children (TEACH<sup>13</sup>)</p>
Children >6 years	<p><i>Speech perception:</i></p> <p>BE. standard adult word lists</p> <p>BF. Banford-Kowal-Bench Sentences (BKB<sup>5,39</sup>)</p> <p>BG. Hearing In Noise Test-Children (HINT-C<sup>6</sup>)</p> <p>BH. Detection of word-final plurality (UWO Plurals Test)<sup>35</sup></p> <p>BI. Loudness rating<sup>7</sup>:</p> <p>BJ. Paired-comparison judgment<sup>8</sup></p> <p>BK. Ling 6 Sounds Test<sup>40</sup></p>	<p><i>Parents' report:</i></p> <p>BL. Children's Abbreviated Profile of Hearing Aid Benefit (CA-PHAB<sup>20</sup>)</p> <p>BM. Parents' Evaluation of Aural/oral Performance of Children (PEACH<sup>12</sup>)</p> <p><i>Teachers' report:</i></p> <p>BN. Screening Instrument For Targeting Educational Risk (SIFTER<sup>21</sup>)</p> <p>BO. Teachers' Evaluation of Aural/oral Performance of Children (TEACH<sup>13</sup>)</p> <p><i>Self report:</i></p> <p>BP. Children's Abbreviated Profile of Hearing Aid Benefit (CA-PHAB<sup>20</sup>)</p> <p>BQ. Client Oriented Scale of Improvement for Children (COSI-C<sup>22</sup>)</p> <p>BR. Hearing Performance Inventory for Children (HPIC<sup>23</sup>)</p> <p>BS. Listening Inventory for Education (LIFE<sup>24</sup>)</p> <p>BT. Self-Evaluation of Listening Function (SELF<sup>13</sup>)</p>

\*Please see Section 6.2.3 for a full description of potential error sources that are associated with aided audiograms.

Reported tools that have published information on normative data and critical differences include the ABEL<sup>14</sup>, CA-PHAB<sup>20</sup>, MAIS<sup>17</sup>, PEACH<sup>12</sup>, TEACH<sup>13</sup>, and LittlEARS<sup>36,37</sup>.

### Summary of Evidence for Outcomes Assessment

Rec	Evidence	Source	Level	Grade	EF/EV	Adult
1	Parental reports are sensitive to differences in frequency response in hearing aids for infants and young children with severe and profound hearing loss.	13	3	B	EV	
1	Self-reports are sensitive to differences in hearing aid gains for school-aged children.	26	2	A	EV	
		29	2	A	EF	
		28	3	B		

2	Difference in hearing aid gain of more than 3 dB results in a difference in loudness comfort, intelligibility judgment and everyday functioning.	26	2	A	EF	
		28	3	B	EV	
2	Difference in hearing aid frequency response of more than 3 dB/octave results in a difference in everyday functioning.	28	3	B	EV	
3	Paired-comparison judgments can be used reliably to evaluate differences in gain-frequency response, but not output compression characteristics in hearing aids for school-aged children.	13	3	B	EF	
		30	3	B	EV	
		26	2	A		
		29	2	A		

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## 8. MANAGEMENT/FOLLOW-UP AND REFERRALS

### Objectives

The prescription of hearing aids for children is an on-going, interdisciplinary process. Following the initial diagnosis

and hearing aid fitting, continued audiologic evaluation and adjustment of amplification settings based on the updated audiologic data should be prioritized. Audiologists should continue to provide informational and adjustment counseling to support consistent hearing aid use and facilitate understanding of hearing aid care and maintenance. Additional objectives as part of the on-going management process include diagnostic medical evaluations, connection with education and early intervention resources, and financial support resources.

## Recommendations for Management, Follow-up and Referral

On-going audiologic evaluation and adjustment of amplification are necessary to ensure consistent audibility over time. Hearing aid fittings for infants and young children are often based on limited electrophysiological or behavioral data. Children are more likely than adults to experience fluctuation or progression of hearing loss over time, in addition to normal physical growth that can influence the acoustics of the hearing aid fitting and earmold adequacy.

Patient/family education and adjustment counseling (social and emotional support) should be provided as part of routine audiologic follow-up to ensure children and their parents and caregivers have the knowledge and assistance necessary to support consistent use of intervention strategies, including but not limited to hearing aid and other technology use and communication strategies as well as healthy psychosocial development.

Referral for medical evaluations is important for identifying potential medical conditions related to the hearing loss, as well as the likelihood for progression or precautions that could minimize likelihood of progressive hearing loss (i.e. limiting participation in contact sports for children with enlarged vestibular aqueduct). Referral to otolaryngology, ophthalmology and medical genetics should be provided for all children who are hard of hearing.

Support for accessing early intervention and academic support should be facilitated, including timely referral to early intervention for infants and young children who are hard of hearing. Educational and academic support also include supporting Individualized Family Service Plans/Individualized Education Plans (IEP/IFSP) and performing periodic assessments of the child’s listening situations and needs to determine candidacy for hearing assistance technology and to optimize use of the technology.

Resources for financial support and funding to offset the cost of hearing aids should be provided, as concern for the cost of devices is often cited by parents as delaying the initiation of amplification.

Parent-to-parent support should be offered to families and caregivers of children with hearing loss. Special consideration should be given to matching families based on support needs, hearing loss characteristics and other factors.

### Summary of Evidence for Management, Follow-up, and Referral

Rec	Evidence	Source	Level	Grade	EF/EV	Adult
1	Ongoing audiologic assessment and hearing aid verification are necessary to maintain audibility with the potential for fluctuation or progression of hearing loss, in addition to normal ear canal growth.	1 2	4	C	EV EF	
2	Informational and adjustment counseling should be provided on an on-going basis to support consistent use of amplification.	3	4	C	EF/EV	

3	Referral for medical evaluations, including otolaryngology, ophthalmology and medical genetics should occur for children with hearing loss.	4	5	D		
4	Referral for early intervention and educational services should occur in a timely manner in compliance with local, state and federal regulations.	4	5	D		
5	Referral for financial programs and funding resources should be provided to avoid delays in the initiation of amplification.	5	4	C	EF/EV	
6	Parent-to-parent support should be offered to families and caregivers of children with hearing loss.	6 7	4	C	EV EV	

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## 9. USE OF HEARING AIDS WITH OTHER ASSISTIVE TECHNOLOGIES

### 9.1 Remote Microphone Hearing Assistance Technology

The American Academy of Audiology has published clinical practice guidelines (CPG) and verification supplements for remote microphone hearing assistance technology. Available for download at [http://www.audiology.org/resources/documentlibrary/Documents/HAT\\_Guidelines\\_Supplement\\_A.pdf](http://www.audiology.org/resources/documentlibrary/Documents/HAT_Guidelines_Supplement_A.pdf) and [http://www.audiology.org/resources/documentlibrary/Documents/20110926\\_HAT\\_GuidelinesSupp\\_B.pdf](http://www.audiology.org/resources/documentlibrary/Documents/20110926_HAT_GuidelinesSupp_B.pdf)

The CPG describes in detail issues surrounding candidacy, personnel, verification, orientation, training and validation procedures and relevant recommendations on these subjects. While all children wearing hearing aids (or being considered for amplification) are described as candidates for remote microphone technologies, the clinical practice guidelines recognize that the utilization of these technologies increases at school age. Although hearing assistance technology is commonly considered in school age children it is appropriate to employ an off-site microphone in cases where feedback is an issue in infant ears, and communication is happening at a distance or under unfavorable conditions (i.e., during car travel, in a daycare environment, etc.). The output delivered to the ear must be verified when signals are delivered via a remote microphone. See supplements A and B for verification guidelines. Supplement C is forthcoming.

## 9.2 Cochlear Implants

### Recommendations for Cochlear Implants

Each child who receives a cochlear implant in one ear and who has residual hearing in the other ear should be fit with a hearing aid in that ear for providing bilateral stimulation. Children with bilateral hearing impairment require stimulation in both ears for encouraging auditory development and for performing binaural hearing functions. These functions arise from the effects of head shadow, binaural summation and redundancy, and binaural squelch. The benefits of binaural hearing range from improved speech perception in noise and sound localization to improved functional performance in real life and perceived quality of life. There are binaural benefits when a hearing aid is used with a cochlear implant (bimodal fitting) in the opposite ear. The benefits can be largely attributed to head shadow effects and binaural redundancy, as well as complementary low-frequency cues such as prosody cues, word-boundary identification, and music appreciation.

Bimodal fitting should be provided even when residual hearing in the non-implanted ear is limited to frequencies below 500 Hz. When a hearing aid is combined with a cochlear implant, voice pitch information conveyed by acoustic hearing accounts for the majority of the speech perceptual benefit and language development benefit for children. Even when hearing thresholds at frequencies  $\leq 500$  Hz are between 80 to 100 dB HL, some children show benefits in speech perception when acoustic stimulation is added to electric stimulation. Evidence from adults show benefits even when the acoustic stimulation was restricted to the bandwidth below 150 Hz. This supports the provision of bimodal fitting to children with limited residual hearing in the non-implanted ear. There is currently no direct comparison of the relative efficacy of bimodal fitting and bilateral implantation for children.

The hearing aid should be optimized with the cochlear implant by balancing loudness of sounds between ears. In order to achieve maximal binaural benefits with bimodal hearing, it is important that loudness of sounds heard

simultaneously through each device should be similar.

### Summary of Evidence for Cochlear Implants

Rec	Evidence	Source	Level	Grade	EF/EV	Adult
1	Benefits in speech perception and localization were obtained by children when acoustic amplification was used with electric stimulation (bimodal hearing), consistently across different languages and different test set-ups.	1	3	B	EF	
		2	3	B	EF	
		8	3	B	EF/EV	
		9	3	B	EF	
		10	3	B	EF	
		11	3	B	EF	
2	Children with hearing thresholds of >80 dB HL in low frequencies obtained benefit from bimodal hearing.	8	3	B	EF/EV	
		9	3	B	EF	
2	Acoustic information below 150 Hz improved speech perception with cochlear implants for adults.	6	4	B	EF	Adult
		7	4	B	EF	
2	Acoustic information about voice pitch improved consonant perception for adults with cochlear implants	5	3	B	EF	Adult
2	Acoustic information about voice pitch improved consonant perception for children with cochlear implants	4	3	B	EF	
3	Loudness balance between ears improved performance for adults	3	4	B	EF	Adult
3	Loudness balance and optimized hearing aid frequency response led to increased benefit with bimodal hearing in children	9	3	B	EF/EV	

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