Chapter 14

Amplification & Hearing Assistive Devices (HAT)

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It has been established that children with normal cognitive abilities who gain access to resources designed to maximize their potential before the age of 6 months show stronger language aptitude across all test ages, communication modes, degrees of hearing loss, and socioeconomic status than those children identified after the age of 6 months.

Implementation of the Joint Committee on Infant Hearing (JCIH) statements and the Centers for Disease Control's (CDC) National Goals for Early Hearing Detection and Intervention (EDH,; 2004) have resulted in noteworthy reductions in the age of identification of hearing loss (CDC, 2004). Use of physiologic measures as part of the hearing screening process aims to identify infants suspected of having hearing loss no later than 1 month after birth. Diagnostic assessment to confirm the presence or absence of impairment should be completed no later than 3 months of age. Infants with confirmed hearing loss should be enrolled in appropriate early intervention services no later than 6 months after birth (American Speech-Language-Hearing Association, 2007; CDC, 2004). Early intervention includes medical, audiological, and educational services, which, when synchronized, reduce the likelihood that infants and young children will face delays in the development of language, cognition, and/or socioemotional growth when compared to their normal hearing peers.

It has been established that children with normal cognitive abilities who gain access to resources designed to maximize their potential before the age of 6 months show stronger language aptitude across all test ages, communication modes, degrees of hearing loss, and socioeconomic status than those children identified after the age of 6 months (Bagatto, 2013). Amplification may be seen as a bridge that allows a child to maintain developmental pace with normal hearing children.

Appropriate amplification can provide immediate access to the audible signal that stimulates neural connections throughout the auditory system and brain. As neural connections grow stronger due to the availability of a repetitive, robust acoustic signal, the auditory pathways begin to organize themselves and develop similarly to children with normal hearing. The establishment of neural connections creates the foundation from which spoken language, reading, and academics develop (Madell & Flexor, 2013).

Any technology that allows for neural stimulation of the auditory mechanism may be defined as amplification, including hearing aids, cochlear implants, and hearing assistive technologies (HAT). Higher levels of auditory processing will

NCHAM National Center for Hearing Assessment and Management Utah State University™

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not be achieved, and spoken language, reading skills, and academics will all be compromised when limitations or distortion inhibit access to the audible signal (Madell & Flexor, 2013). The role of the audiologist is to "provide timely fitting and monitoring of amplification, provide family education, counseling, and ongoing participation in the development and implementation of the infant's individualized family service plan" ("Babies & Hearing Loss: A Guide for Providers about Follow-up Medical Care"). This chapter will focus on the fitting verification and validation of products that provide acoustic stimulation via the external auditory canal (hearing aids and HAT).

Neuroplasticity is greatest during the first 3-½ years of life, and as noted earlier, research indicates significant benefits to the auditory pathways when an amplified signal is provided much earlier than this. Our goal is to provide an infant with "full sensory access to the symbols of language" (Madell & Flexor, 2013) at a very early age, so in building our bridge, we must consider:

Photo courtesy of Centers for Disease Control and Prevention

- The nature of the dynamic speech signal within the child's acoustic environment.
- The need to determine amplification needs in light of lack of behavioral information.
- Selection and fitting of hearing aids.
- The importance of the verification process necessary to ensure maximum audibility of the speech signal.
- Validation measures to ensure that appropriate outcomes are being achieved.
- Technological advances that will best serve the child's needs during subsequent developmental stages.

The Dynamic Speech Signal

As audiologists, we may have the impression that the speech signal is rather static and predictable. It is typical to think of the intensity of average conversational speech as approximately 60 dB SPL. This conversational speech intensity exists primarily for speech energy below 1000 Hz approximately 4 feet away from the listener's ear (Madell & Flexor, 2013). The dynamic nature of the speech signal is often overlooked. The intensity of the higher frequency speech sounds necessary for speech intelligibility (between1000 to 3000 Hz) will be softer, falling by 5 to 6 dB per octave. The individual amplitudes of the speech signal fluctuate by about 15 dB above and below the long-term average speech spectrum (LTASS; Madell & Flexor, 2013). Intensity decreases by approximately 6 dB when the distance from the speaker doubles. All of these factors contribute to a very active acoustic signal that we must ensure is audible to the child (Madell & Flexor, 2013). Young children demonstrate a need for more audibility, larger frequency bandwidth, and greater signal to noise ratios (SNR) in order to access enough of the acoustic signal to fully develop language (Crukley & Scollie, 2012). Audiologists must consider all these variables during the fitting process.

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Determining Amplification Needs without Behavioral Threshold Data

As we begin to determine the amplification needs of an infant, often amplified gain and output levels must be determined without the behavioral threshold data that manufacturers and prescriptive formulas require. Intervention cannot be delayed until complete audiometric data is obtained. Initial diagnostic protocols require that threshold estimates be obtained for at least two frequencies in each ear (Bagatto, 2013). These estimates are obtained by physiologic test measures, such as Auditory Steady State Response (ASSR) or more typically Auditory Brainstem Response (ABR). These estimates are typically higher than thresholds obtained during behavioral testing (Bagatto, 2013). Corrections must be made to these estimates in order to predict behavioral thresholds and calculate a starting point for the amplification prescription. ABR measurements are calibrated as decibels normalized hearing (dB nHL). Each manufacturer of ABR equipment maintains its own frequency-specific correction factors, which are deducted from the dB nHL threshold obtained to predict the decibel "estimated" hearing level (dB eHL; Bagatto, 2013).

Once predicted dB eHL data has been obtained, the audiologist will need to determine which prescriptive method—Desired Sensation Level (DSL) or National Acoustic Laboratories (NAL)—will be used to determine desired amplification gain and output levels. Prescriptive approaches provide the audiologist with consistent and measurable targets for gain and output settings intended to maximize the audibility of speech in a variety of environments (McCreery, Bentler, & Roush, 2013). The goal of the DSL fitting formula is to provide an acoustic signal that is both audible and comfortable. DSL prescribes more overall gain than NAL-NL2 and is more commonly used by pediatric audiologists (Madell & Flexor, 2013). Children with moderate to severe sensorineural hearing loss have demonstrated the capability of identifying 80 to 95% of consonants during consonant recognition tasks when DSL prescriptive formulas were used (Crukley & Scollie, 2012). NAL fitting formulas attempt to maximize speech intelligibility by equalizing frequencies that are critical for understanding conversational speech. The formula creates fitting targets that suggest gain requirements based on each frequency's contribution to speech intelligibility (McCreery et al., 2013). Recent research shows that 3-year-old children obtain similar language, speech production, and functional auditory skills with either prescriptive formula (McCreery et al., 2013).

Another factor which must be considered is the acoustic impact the small size of an infant's ear canal has on the amplified signal. The sound pressure level (SPL) of any acoustic signal will be much greater in an infant's ear canal than it would be in the larger ear canal of an adult. The individual intensity differences between infants 2 to 6 months of age and adults will vary dramatically, ranging from +12 to +16 dB (Bagatto, 2013). As the infant matures, the peak resonant frequency of the ear canal will decrease from approximately 6,000 Hz to an adult ear canal average of 2400 Hz. The ear canal and its acoustic properties changes rapidly during the first few years, requiring frequent adjustments to the hearing instrument program. It is important to achieve consistent stimulation to the auditory system by maintaining the intensity of the signals that arrive at the tympanic membrane (Madell & Flexor, 2013).

Selecting and Fitting Hearing Aids

Behind the ear (BTE) hearing instruments are recommended in most cases when fitting infants and toddlers. As mentioned earlier, the degree of hearing loss identified this early is often significant and requires the power and flexibility of this style of device. Flexibility must be considered to allow for refinement of the hearing instrument program as further audiometric data is obtained on the maturing child. The BTE style can receive direct audio input (DAI) of the acoustic signal, providing enhanced audibility of isolated sounds in challenging listening environments. The BTE hearing instrument also offers:

- Locking battery doors to reduce the risk of ingestion of toxic batteries.
- Fixed volume control settings to ensure proper intensity levels are maintained.The ability to provide loaner devices, as needed.
- Pleasing fun additions of color, stickers, or accessories suitable to the age of the patient (Madell & Flexor, 2013).

Earmolds are made of soft materials to reduce leakage of acoustic energy and protect the skin tissue from the risk of trauma that may occur with harder materials. Occasionally, hard acrylic materials are considered when there is a discharge coming from the external or middle ear (Madell & Flexor, 2013). Whenever possible, a spare set of earmolds is advised to support continued use of hearing instruments while the other set of molds is nonfunctional for any reason. To maintain proper fit and performance, earmolds need to be remade:

- Monthly until 6 months of age.
- Bimonthly from 6 to 12 months of age.
- Three to four times per year until the third birthday.
- Anytime there are fit or performance issues.

Infants identified as needing amplification at an early age usually have significant hearing loss across all frequencies, or ear canals that are too small to include large vents (Madell & Flexor, 2013). It should be noted that a vented earmold will change the low-frequency acoustic properties of devices.

Retention of the BTE instrument on the baby's tiny ear can be a challenge that may be helped by using:

- Pediatric-sized earhooks.
- Double-sided tape on the device.
- Extra stiff moisture resistant tubing on the earmold.
- A product called "Huggie Aids."

For added security, a variety of retention cables are available to ensure that a hearing aid that falls out of the ear is not lost forever.

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Huggie Aids, from seattlerusts.blogspot.com

Retention Cable, from The Bebopshop https://www.etsy.com/shop/thebebopshop?ref=unav_listing-r

The Importance of Verification

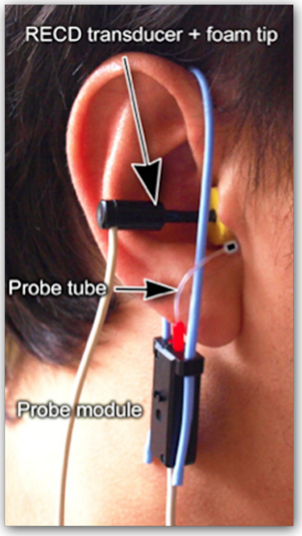
The only way to ensure that amplification provides full sensory access without over-amplification during this period of rapid

If amplification is to be our "bridge" to acquisition of the acoustic cues required to stimulate neural connections within the auditory system, it is critical to recognize that objective measurement is the ONLY way we can be sure our "bridge" has provided this necessary foundational support.

growth is to regularly evaluate the ear canal resonance and actively verify the amplified response using a probe tube microphone (McCreery et al., 2013). Strauss and van Dijk (2008) found that nearly 50% of children in their study were provided amplification without benefit of verification (McCreery et al., 2013). If amplification is to be our "bridge" to acquisition of the acoustic cues required to stimulate neural connections within the auditory system, it is critical to recognize that objective measurement is the ONLY way we can be sure our "bridge" has provided this necessary foundational support. Real ear to coupler difference (RECD) measurements at regular intervals provide the necessary objective measurement.

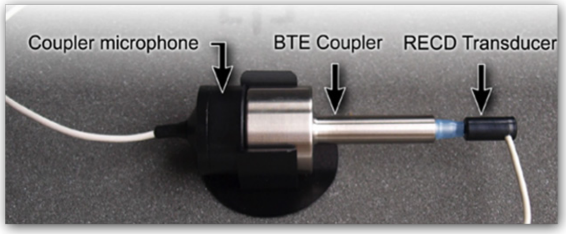
RECD measures are a quick way to capture the child's ear canal resonance and calculate the difference between its size and shape and the standard 2 cc coupler used in electroacoustic testing. Once the RECD has been obtained, the clinician may adjust the program and verify the audibility of the child's hearing instrument settings within the environment of a controlled hearing instrument test box. The RECD allows prediction of the output of the hearing instrument to within about 2 dB of ear level real ear measurements (Seewald, Moodie, Sinclair, & Scollie, 1999). Since access to the speech signal is so critical to the developmental needs of the preverbal patient who cannot provide feedback about the hearing aid fitting, objective verification protocols have emerged as the standard of care for this population.

The initial RECD can be completed as part of the diagnostic protocol when electrophysiologic studies (i.e., ABR, ASSR) are being done, since the child will be calm or asleep during that time. It can also be completed at any time prior to the initial hearing aid fitting. To facilitate the efficiency of this test, the probe tube may be pre-attached to the foam tip of the RECD transducer with a thin strip of plastic wrap (Bagatto, 2013). In this way, the probe tube, which is positioned to extend 2-4 mm beyond the tip of the foam insert, is simultaneously inserted into the child's ear canal along with the insert transducers used for other testing.



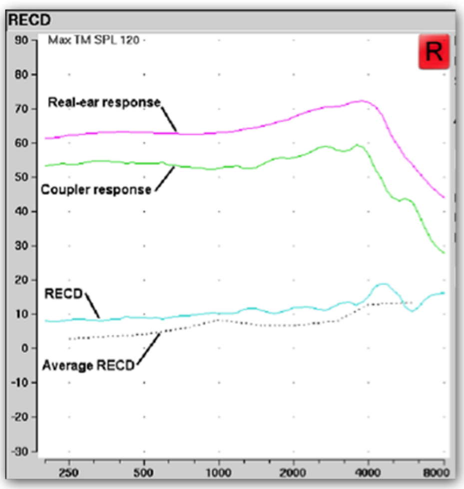
From Audioscan Verifit Manual.

After the RECD transducer and probe tube are inserted into the child's ear canal and the foam tip is fully expanded, a sound is emitted from the transducer. The probe tube measures the acoustic properties of the canal and creates a real ear response curve. The same transducer is then attached to the 2 cc coupler, and the same sound is produced to generate a coupler response curve.



From Audioscan Verifit Manual.

After both measurements have been obtained, the coupler response is subtracted from the real ear response to obtain the RECD. The pediatric ear canal should create SPL levels that are substantially higher than the standard adult size coupler; therefore, the RECD values generated should be positive numbers. If negative values occur in a healthy pediatric ear canal (without middle ear effusion, PE tubes, or perforated tympanic membrane), they should be considered suspect. Negative values below 1 kHz suggest that the acoustic seal was not adequate. The audiologist should ensure that the foam tip has fully expanded. It may be necessary to increase the size of the foam tip or apply lubricant to improve its seal in the ear canal. Negative values above 1 kHz may be suggestive of a blocked tip or kinked probe tube (Audioscan, 2014).



From Audioscan Verifit Manual.

With the RECD values in hand, the audiologist can begin programming the hearing instrument. The instrument is connected to the manufacturer's programming software in the usual way and is simultaneously coupled to the 2 cc coupler and placed inside the calibrated test box. The audiologist proceeds by selecting a preferred prescriptive formula in the hearing instrument test box software and applies the measured RECD data to the fitting formula. (NOTE: Some electroacoustic units will automatically apply the RECD values if measurements were performed on the same day as the fitting.) Both DSL 5.0 and NAL-NL2 provide fitting targets for soft, moderate, and loud speech input levels. The hearing instrument should be adjusted, so the output of speech or speech-like stimuli comes within + 5 dB of these targets.

Another critical step is to verify the maximum power output (MPO) of the device. This is accomplished as the final step of the process by measuring the MPO in the test box and adjusting the output of the device until it is within the appropriate range of the fitting formula targets. At the conclusion of this process, the device will provide the child with full access to long-term average conversational levels while maintaining comfort for loud sounds.

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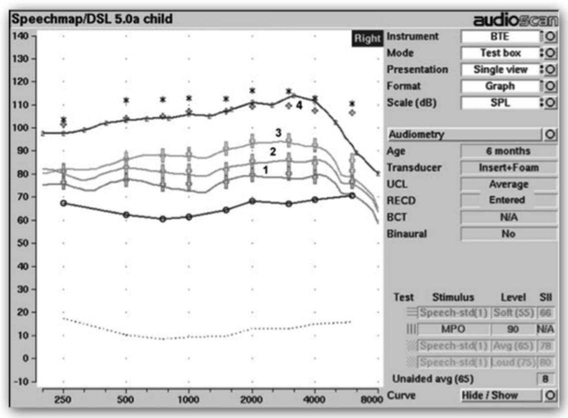


After the initial fitting, the RECD should be re-measured and the hearing instrument reprogrammed each time a new earmold is required. The decision that a new ear mold is required means that the ear canal acoustics have changed significantly, resulting in a reduction in the level of the signal arriving at the tympanic membrane (Bagatto & Moodie, 2014). The DSL prescriptive method does provide average RECD values for the infant's age in months when the audiologist cannot obtain a measured RECD. These predicted values have been shown to be helpful, in some cases, but should not be used as a replacement for the measured RECD when fitting infants. It should remain the audiologist's protocol to obtain the child's RECD whenever possible (Bagatto & Moodie, 2014).

We can't assume that all of the needs of the child are being met simply by reaching audibility goals. Validation procedures are vital to help us determine if amplification is really helping the infant gain enough access to sound to meet the development goals we have established. Infants rely on their audiologist to achieve the best possible outcomes on their behalf.

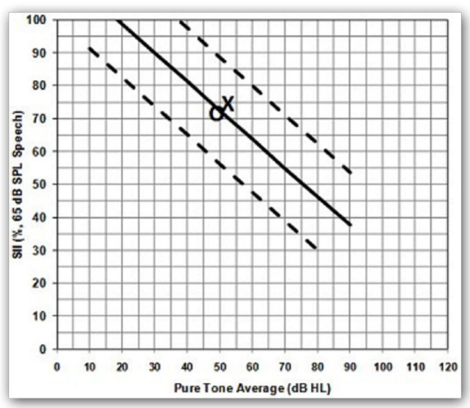
Armed with a visual representation of the intensity of the speech signal arriving at the tympanic membrane, the audiologist must consider the impact that audibility—or more importantly the lack of audibility—has on the child's ability to learn language. The available data can be used to provide insight into the acoustic, phonetic cues and phonemes that are accessible to the child (Madell & Flexor, 2013). Most electroacoustic test units will provide a predicted Speech Intelligibility Index (SII), which is calculated based on each discrete frequency band's contribution to speech understanding. The SII weighted percentage may be used to predict communicative abilities in children.

Stiles, Bentler, and McGregor (2012) associated SII scores with patterns of vocabulary development in children, suggesting that aided SII scores that were higher than 65% resulted in better vocabulary development for children with mild to moderately severe loss. Some caution should be exercised while analyzing the available data to predict speech understanding if only the SII's impact is considered. Certainly, lack of audibility of the signal will influence the child's ability to learn. It is in the pediatric patient's best interest to have maximal access to the speech signal. However, we must also consider the effect of reduced spectral and temporal resolution on sound identification and speech understanding. Difficulties with discrimination, especially in the presence of noise, may remain despite high levels of audibility (Madell & Flexor, 2013).

Validation Is Vital

The role of the audiologist does not end when hearing instruments and hearing assistive technology have been appropriately fitted. Continued monitoring of auditory thresholds permits increased reliability of responses, allowing further refinement of technology settings to ensure prescriptive auditory targets are met. Regular electroacoustic analysis in a hearing aid test box is crucial to confirm devices are functioning properly at all times. Loaner devices need to be available, so that auditory development is not delayed while the child's devices are being repaired. This monitoring process must include validation measures to confirm that the child's functional auditory capacity has been optimized. We can't assume that all of the needs of the child are being met simply by reaching audibility goals. Validation procedures are vital to help us determine if amplification is really helping the infant gain enough access to sound to meet the development goals we have established.

Infants rely on their audiologist to achieve the best possible outcomes on their behalf. Use of evidenced-based measures to systematically assess performance and development must be considered the standard of care. One such tool is the University of Ontario's Pediatric Audiologic Monitoring Protocol (UWO PedAMP). A portion of this protocol focuses on functional outcomes for children up to 6 years old, while the rest of the protocol focuses on development and success of the process. UWO PedAMP assumes that RECD measurements have been used, and prescriptive targets are met. They recommend use of an SII normative value worksheet to help determine if amplification devices are delivering the proper amount of gain by comparing the aided SII value to those of children with similar pure tone averages (Bagatto & Mueller, 2012).



The Aided Speech Intelligibility Index (SII) Normative Values Worksheet from the UWO PedAMP, *http://www.audiologyonline.com/articles/20q-baby-steps-following-verification-783*

An additional challenge we face when fitting amplification on children is determining which of today's innovative technologies and styles will best meet the needs of the pediatric patient.

Subjective reports from the child's caregiver(s) provide information regarding performance outside the clinical environment. This measurement tool uses data on auditory behavior to permit caregivers to report on infants who are too young to provide speech information or on medically involved, nonverbal children (Bagatto & Mueller, 2012).

While there are a number of other questionnaires that collect similar information, the normative data supplied by the UWO PedAMP makes it particularly attractive for use with this population. The Little EARSâ Auditory questionnaire and the Parents Evaluation of Auditory/Oral Performance of Children (PEACH) are used as collection tools. Both allow the calculation of a score that clinicians can compare to normative ranges. An additional questionnaire assesses:

- Acceptance of hearing aids.
- Auditory performance for different sound levels.
- Effectiveness of service delivery.
- Overall satisfaction.Families' feelings regarding the quality and success of the process (Bagatto & Mueller, 2012).

The UWO PedAMP manual can be found at www.dslio.com.

Photo courtesy of iwontweargrey.blogspot.com

Technological Advances That Will Best Serve the Child

An additional challenge we face when fitting amplification on children is determining which of today's innovative technologies and styles will best meet the needs of the pediatric patient. Research regarding the efficacy of advanced hearing instruments is unable to keep pace with the speed of product development. Research study outcomes so useful in providing guidance to the audiologist are sorely lacking for the pediatric population (McCreery, 2008). As a result, evidence must be carefully reviewed as new research becomes available. Each new technology must be assessed based on the individual needs and environment of the child. Keeping in mind that our primary objective is to assist in the development of the child's language, we must consider if a particular technology:

- Offers the broadest frequency response to maximize the signal that's delivered.
- Provides the child with the high signal-to-noise ratio needed to understand speech in complex listening environments.
- Will positively impact the child's ability to learn using critical incidental hearing opportunities.

The only way to determine if these objectives have been met is verification of functional hearing abilities both in quiet and in noise, regular monitoring of device performance, and post-fitting validation to determine whether the technology had a positive or negative impact on the language development and cognitive progress of the child (Bagatto, 2013).

Every child's hearing instrument should be capable of receiving wireless transmission of the acoustic signal. The variability associated with the intensity of the speech signal is extensive. Maintaining audibility of elements critical to understanding speech at increased distances without the interference of competing environmental

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noise is next to impossible. Wireless transmission using FM, BluetoothTM, or electromagnetic induction offers a means of transmitting desired signals over significant distances with limited impact on the quality of that signal. This will provide enhanced access to speech whenever a child is more than 1 meter from the speaker or attempting to follow one speaker in a noisy, multitalker environment.(Madell & Flexor, 2013). Wireless transmission settings for the intensity of the primary signal and position of a remote microphone will be determined based on the intended plan for following speech in that environment.

For instance, if the goal is for a child to hear and understand one speaker, then that speaker will wear a remote microphone, and the hearing instrument should receive and amplify only that signal. Device settings that detect and amplify the remote microphone signal while still providing amplification from the microphone on the hearing aid will be of benefit when there are multiple communicators. Using both remote and hearing aid microphones will provide access to incidental environmental sounds that have been shown to facilitate language and learning. When this type of configuration is desired, it should be recognized that an equal mix of the two input signals will degrade intelligibility (Madell & Flexor, 2013). To reduce this impact, settings that give priority to the remote microphone signal when it is present—and/or reduces the intensity of the ear level microphone output—can provide an opportunity to benefit from both signal types.

Compression of the amplified signal is another technology that should be considered as part of the initial programming process. The nature of cochlear hearing loss results in a disproportionate ability to hear loud sounds compared to soft sounds. Linear amplification of soft sounds without compression can result in over-amplification of loud sounds, which remain audible despite the degree of hearing loss. When wide dynamic compression is applied to the input signal, soft sounds, such as the high-frequency consonants critical for speech intelligibility, are enhanced and amplified more than louder sounds. Compression provides increased access to important acoustic cues, while ensuring that louder sounds are not uncomfortable or loud enough to cause damage to residual hearing. Infants and young children are unable to control the volume of their device. Therefore the use of compression to ensure appropriate access to sounds is advised. Both DSL and NAL prescriptive formulas include recommendations for compression settings for all degrees of hearing loss.

The greatest challenge for every hearing-impaired patient is the ability to understand speech in loud, noisy, and/or reverberant environments. As adults, our language is fully developed, so we are able to use auditory closure skills to follow the gist of the conversation, even in a moderately noisy environment. Children in the process of learning language have undeveloped auditory closure skills. As a result, they require higher signal-to-noise ratios to successfully comprehend speech in noise (Madell & Flexor, 20130). On any given day, children can be exposed to background noise levels ranging from 40 to 80 dBA (Crukley & Scollie, 2012). Wireless transmission of the signal can assist in this situation, but there will undoubtedly be occasions when the child will need to hear and understand speech in challenging environments.

Recommendations for management of hearing in noise for children may vary, depending on the circumstances. For instance, the goal of a hearing instrument's settings may be to provide comfort in a loud environment, or it may be to enhance speech understanding in moderately noisy environments. Both goals will require different setting targets of the primary program. DSL 5.0 can provide fitting targets for both quiet and noisy settings. Either fitting formula for hearing in noise should be applied by enabling a second memory

We must first understand the makeup of acoustic signals to understand the potential benefit and impact that advanced noise management technology can have on interfering sounds. Noise is any unwanted sound that hinders audibility of the primary signal.

in the hearing instrument. For improved comfort in noisy surroundings, the program should provide an alternate frequency response with reduced low-frequency gain and increased compression ratios.

This program can be activated when the child is in a loud environment to alleviate loudness discomfort. When the goal is to improve the clarity of speech in noise, the secondary program prescribes less gain in the low frequencies but maintains prescribed audibility of those frequencies known to provide the greatest assistance to speech intelligibility. Vocal intensities naturally rise when speaking in noise, so the compression threshold is increased by 10 dB to decrease the amount of gain added to softer input levels, which consist mostly of interfering noise (Crukley & Scollie, 2012). Current hearing instrument technology that allows automatic program switching may support the use of these additional adjustments by allowing them to automatically engage only when the noise levels in the environment meet a specific criterion.

We must first understand the makeup of acoustic signals to understand the potential benefit and impact that advanced noise management technology can have on interfering sounds. Noise is any unwanted sound that hinders audibility of the primary signal. One kind of noise may be a speaker talking at the same time as the speaker the child is trying to understand. Another kind of noise is transient or nontransient signals with an intensity and frequency spectrum similar to speech. Finally, noise may result from the reflection of sound off walls, doors, windows, etc. that arrive at the microphone later than the original signal.

Adaptive digital noise reduction (DNR) acts upon nontransient (steady state) acoustic signals. Noise sources that are repetitive in their intensity and frequency modulation (such as, air conditioner fans, refrigerators, motors, etc.) are detected by technology, which modifies the incoming signal in an attempt to separate the speech signal from the steady-state noise. Adults report improved listening comfort when adaptive DNR algorithms are enabled in hearing aids and prefer it despite the fact that improvements in speech intelligibility have not been documented. Research on adults has shown that adaptive DNR reduces listening effort, which may improve working memory by freeing up cognitive resources for other processing tasks (Sarampalis et al., 2009).

When children, ages 5 to 12, were evaluated, adaptive DNR did not appear to diminish speech understanding. There is no reason to believe that the benefits DNR provides to adults would not carryover to a younger population. Current literature recommends enabling DNR technology when fitting amplification on children (Bagatto, 2013). Transient noise reduction, which acts upon sudden loud impulse sounds, does not appear to reduce intelligibility and can also be considered beneficial for children (Bagatto, 2013).

Directional microphones enhance speech understanding in noise by improving the audibility of speech in relation to unwanted, interfering noise. This is known as the signal-to-noise ratio (SNR). The microphone sensitivity is reduced for sound sources arriving from the rear or side of the device, enhancing audibility of the signal arriving from the front. For this technology to be effective, the user must be able to look in the direction of the primary sound source. The literature cites numerous examples documenting the ability of directional microphones to improve the SNR and provide the adult listener with improved speech intelligibility in noise. When children are evaluated using directional microphones, they achieve results that are similar to adults. While children may obtain the same directional advantage for speech presented from the front, however, they will experience less than optimal audibility if speech is presented from behind or to the side (Bagatto, 2013). There does not appear to be a clear-cut recommendation in current literature as to what age directional microphone technology should be considered.

Audiologists must fully understand the function and variations of manufacturers' microphone technology. In conjunction with the child's caregivers and teachers, they must determine if the child is in an environment that supports a directional advantage.

Infants do not consistently turn their heads to look at the speaker, resulting in a less than optimal acoustic signal for the language-impoverished child to encode (Bagatto, 2013). The head-turning behavior needed to support directional microphone advantages will become consistent at some point between 11 to 78 months (Madell & Flexor, 2013). A review of existing research suggests that automatic-switching directional microphones may be enabled as early as 6 months—hypothesizing that at this age, a child is able to control their own head movement. The child will learn that the speech signal becomes clearer and easier to understand when their head is turned in the direction of the primary speaker (Madell & Flexor, 2013). Those advocating later activation—when the child is old enough to consistently look at the speaker during conversation (6 to 7 years old)—note that children need to hear environmental noise and distant speech from all directions in order to:

- Fully develop neural connections.
- Access incidental learning opportunities.
- Maximize language and auditory processing development.

Audiologists must fully understand the function and variations of manufacturers' microphone technology. In conjunction with the child's caregivers and teachers, they must determine if the child is in an environment that supports a directional advantage. Only verification, monitoring, and validation of the child's functional performance with the device will provide case-by case conclusions regarding the impact.

Photo courtesy of Pinterest.com

Frequency-lowering technology is designed to provide the hearing-impaired patient access to high-frequency acoustic signals when the degree of hearing loss restricts audibility, or when auditory dysfunction results in distortion of the amplified signal. Two methods are used to shift high-frequency signals into a lower-frequency region. Both are an effort to provide better access to the signal and improve speech intelligibility.

Frequency transposition removes a frequency region from the signal and reintroduces the amplified signal in the lower frequencies. With this technology, the amplified high-frequency signal shares the spectrum with lower-frequency signals. Frequency compression maintains the tonotopic organization of the frequency response, while compressing the high-frequency signals into lower frequencies. Frequency transposition may result in ambiguity as to which frequency should receive primary attention Frequency compression may not have sufficient resolution to identify the original speech spectrum of the stimulus (Madell & Flexor, 2013).

Research findings have not clearly demonstrated the effectiveness of this technology. A review of the literature does find some research that supports the benefit of added intelligibility resulting from recovery of high-frequency signals, while other studies report very little benefit. It remains unclear how to adjust this technology in order to optimize the individual's performance. Until more conclusive evidence is reported, or the child is old enough to undergo functional speech measures that demonstrate benefit, it is not recommended that frequency-lowering technology be employed for the pediatric population (Madell & Flexor, 2013). An alternative to frequency-lowering technology is the use of extended high-frequency bandwidth hearing aids, which extend the frequency response to 9000 Hz. Current extended high-frequency devices have been shown to improve identification of plural and possessive phrases in English by providing audibility of the /s/ sound (American Academy of Audiology, 2013).

Digital feedback suppression (DFS) in hearing instruments can provide an effective means of controlling feedback while enabling an additional 10 to 15 dB of gain for soft high-frequency sounds (Madell & Flexor, 2013). The increased gain provides significant benefit by providing access to a broader frequency response that enhances audibility of high-frequency sounds. DFS is considered beneficial when it allows the audiologist to achieve higher levels of audibility and greater access to speech sounds than would otherwise be possible. The application of DFS with some, but not all, digital platforms may actually alter the frequency response and gain settings of the device, reducing feedback by reducing high-frequency gain. When this is the case, the child will obtain less audibility of the speech signal when DFS is activated. For this reason, verification of the amplified signal with DFS enabled is necessary to confirm its impact (American Academy of Audiology, 2013).

Hearing Assistive Technology (HAT)

The technological advancements available in today's hearing instruments are not sophisticated enough to overcome the negative consequences of complex listening environments. Limitations that result from distance from the speaker, interfering noise, and reverberation must also be managed in order to obtain optimum audibility in these adverse settings. To reach our objective of enhancing the signal-to-noise ratio, we turn to peripheral amplification devices that couple with the hearing instruments to optimize the desired signal. A variety of HAT offer the listener improvements to hearing:

- In the classroom.
- In the school lunchroom or a noisy restaurant.
- In a reverberant auditorium or large room.
- On the telephone.
- While using audiovisual technology (TV, stereo, computers).

FM technology consists of a wireless receiver that is integrated, or attaches into, the BTE aid and picks up the FM signal transmitted from a remote microphone. The remote microphone is used to transmit the speech signal across large distances without loss of the loudness of the signal. Since the sensitivity of the transmitting remote microphone diminishes significantly for signals more than about 1 foot away, it eliminates a considerable amount of interfering noise. This improves the signal-to-noise ratio of the primary signal heard by the child. Accessories can be purchased that allow the remote microphone to be plugged into audiovisual equipment (TV, stereo, computer), so that the child hears only the direct audio-input (DAI) of the peripheral signal that is relayed by the transmitting remote microphone.

Photo courtesy of Octicon A/S

The technological advancements available in today's hearing instruments are not sophisticated enough to overcome the negative consequences of complex listening environments. Limitations that result from distance from the speaker, interfering noise, and reverberation must also be managed in order to obtain optimum audibility in these adverse settings.

Pediatric patients and their families entrust their futures to the team of healthcare professionals committed to providing them functional access to the sounds that connect the child to their world. This trust cannot be overstated, and audiologists should never take their role lightly.

Hearing instrument manufacturers are taking advantage of the rapid advances they observe in today's "smart" communication devices and are constantly seeking new ways to integrate these technologies into hearing aids. BluetoothTM streamers can be used as an alternative receiver for input of the remote signal into the device. When streamers are worn, the input of the transmitting signal is received by the streamer, converted to an electromagnetic signal that can be picked up by the telecoil, and changed to an amplified acoustic signal that is heard in the child's amplification device. BluetoothTM streamers require a transmitted acoustic signal from a compatible remote microphone or any device that emits a BluetoothTM signal. Recently, hearing instruments that integrate directly with wireless communication and audiovisual devices for seamless audibility of the desired signal without the need for additional accessories have entered the marketplace. Advances in the variety and availability of HAT are swift, and it is recommended that the reader consult each device manufacturer's website to learn the current state of technology available.

It is critical to verify the appropriateness of the intensity and frequency response of the HAT signal, because ultimately, the amplified signal is delivered into the child's ear. This can be accomplished by performing:

- Electroacoustic analysis.
- Real-ear probe microphone measures.
- Behavioral measures, such as sound-field aided speech recognition.

Validation continues as a vital part of the ongoing process to demonstrate the benefits, and at times limitations, that use of assistive technology has on performance. The use of HAT in infants and toddlers requires a balance that allows for its use in educational and adverse listening environments with an awareness of the need to hear other environmental signals for incidental learning experiences and neural development of the auditory processes. Validation measures should be conducted using objective test materials in the typical listening environment, rather than the sound suite, to obtain a realistic picture of function. Use of HAT should also be validated subjectively by parents, teachers, and caregivers using questionnaires (American-Speech-Language-Hearing Association, 2015).

Conclusion

Pediatric patients and their families entrust their futures to the team of healthcare professionals committed to providing them functional access to the sounds that connect the child to their world. This trust cannot be overstated, and audiologists should never take their role lightly. The acquisition of sounds in their environment:

- Provides the stimulus needed for neural development of the auditory system, which in turn makes language available.
- Allows children access to the resources needed for academic success and learning throughout their lives.
- Engages them in rich social environments.
- Supports mental health.
- Opens doors that lead to viable career opportunities.
- Equips them for a productive life.

Every infant is counting on you to follow established, evidenced-based protocols to efficiently and effectively provide for their needs. It is vital that all audiologists working with children remain diligent, constantly educating themselves on state-of-the-art technology, diagnostic, and habilitative techniques, so they will make the best recommendations on behalf of their patients. Audiologists must recognize that they are the single most qualified professional to build the "bridge" that links a child to the world of sound. Construction of a solid foundational support for our bridge requires use of those protocols of verification, functional assessment, and validation known to result in full sensory access to the sounds of language.

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