

# Amplification Considerations for Children With Minimal or Mild Bilateral Hearing Loss and Unilateral Hearing Loss

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Children with minimal or mild bilateral hearing loss and unilateral hearing loss are at higher risk for academic, speech-language, and social-emotional difficulties than their normal hearing peers. The choice to fit infants with moderate or greater degrees of bilateral hearing loss has been standard practice for most clinicians, but for those with minimal or mild bilateral hearing loss or unilateral hearing loss, the fitting of hearing technology must be based on limited data. Evidence does not yet exist to support all the management decisions that an audiologist must make upon identifying an infant with minimal or

mild bilateral hearing loss or unilateral hearing loss. It is not yet known which children are at the greatest risk for educational problems nor is it known if the provision of early amplification in this population will help a child avoid later difficulties. Some of these considerations and current hearing technology options for children with minimal or mild bilateral hearing loss or unilateral hearing loss are reviewed in this article.

**Keywords:** hearing aids; minimal hearing loss; mild bilateral hearing loss; unilateral hearing loss; children

Children with minimal or mild bilateral hearing loss (MBHL) and unilateral hearing loss (UHL) are at higher risk for academic, speech-language, and social-emotional difficulties than their normal hearing peers.<sup>1-6</sup> The exact reasons for these difficulties are still unknown; however, it is reasonable to assume that they result, at least in part, from the listening problems encountered by these children throughout their development. Therefore, the primary role of audiologists working with children who have MBHL or UHL is the selection and fitting of hearing technology.

The category of minimal hearing is defined differently by different sources. However, a common definition includes (a) permanent bilateral hearing

loss: average air conduction (AC) at 500, 1000, and 2000 Hz between 20 to 40 dB; (b) high-frequency hearing loss: AC thresholds greater than 25 dB at 2 or more frequencies at or above 2000 Hz; and (c) unilateral hearing loss: average AC thresholds of 20 dB or greater in the affected ear with normal hearing in the other ear.<sup>1</sup>

Before the implementation of universal newborn hearing screening, most children with these minimal degrees of hearing loss were not identified until they were school aged.<sup>7</sup> Although not all infants with MBHL or UHL will be identified in the newborn period,<sup>8</sup> many audiologists find themselves in the challenging role of counseling families about the potential effect of these losses and informing them about available hearing technologies. Although the choice to fit infants with moderate or greater degrees of bilateral hearing loss has been standard practice for most clinicians, the decision of whether or not to fit hearing technology on children with MBHL or UHL is less clear. The following discussion reviews some of the considerations that guide our clinical decision making in this area.

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## Auditory Considerations in UHL and MBHL

Evidence is not yet available to support all the management decisions that an audiologist must make on identifying an infant with MBHL or UHL. For example, we do not yet know which children are at greatest risk for educational problems nor do we know which interventions are most effective at ameliorating these problems. However, there are auditory and acoustic considerations that help guide our clinical decisions for children who have minimal degrees of hearing loss.

### Auditory Deprivation

It is likely that many children with MBHL and UHL will not be fit with hearing technology as infants, and if at all, perhaps not until they are school aged. This decision may be the result of late identification of minimal hearing loss,<sup>8</sup> the audiologist's decision to wait to obtain more audiologic information, or the parent's choice. An unresolved clinical question for the audiologist is whether a decision not to fit a child early will affect later potential success with amplification.

Auditory deprivation has been described as a systematic decrease over time in performance associated with the reduced availability of acoustic information.<sup>9</sup> Maturation or atrophy of the central auditory system is dependent on exposure to auditory stimuli. Reorganization of the auditory system can take place following a period of reduced stimulation (deprivation) or following a period after the introduction of auditory stimuli such as amplification.<sup>10</sup>

Late-onset auditory deprivation is the phenomenon in which the speech recognition abilities of an unaided ear will decline over time in contrast to the aided ear, which remains stable. This phenomenon has been shown to occur in adults<sup>11</sup> and in children.<sup>12</sup> Gelfand and Silman<sup>12</sup> found that children with moderate bilateral hearing loss who were monaurally aided demonstrated a significant decrement in word recognition performance in their unaided ears for a period of more than 4 years. The mean ages of children at the initial test and on retest were approximately 6 years and 13 years, respectively. The authors surmised that although children with moderate hearing loss have access to some auditory input, the lack of adequate speech stimulation could still lead to auditory deprivation effects. Grimault

et al<sup>10</sup> found a positive correlation between length of time fitted with amplification in children and their performance on speech recognition testing. That is, adolescents with mild to severe degrees of hearing loss who were fit with binaural amplification for longer periods had better speech recognition than adolescents who were fit for shorter periods. They speculated that these findings might have resulted from a limited time of auditory deprivation prior to amplification and/or the ability of the children via their hearing aids to have access to speech cues and to allow for central auditory system maturation. Hattori<sup>13</sup> also studied children with bilateral hearing loss who were fit monaurally (nonalternating), monaurally (alternating between ears), or binaurally. Although he found an improvement over time in the ears of both monaurally and binaurally fit children, greater improvement in performance was found in the aided ears of the monaurally fit children relative to their unaided ears.

Although these studies evaluated the abilities of children with bilateral hearing loss, the implications of the results for monaurally fit children might be relevant to children with UHL. Recently, Silverman et al<sup>14</sup> reported that over time, word-recognition performance declined in the poorer ear of adults with asymmetric sensorineural hearing loss and no amplification, whereas in a comparison group who wore amplification, word recognition abilities in the good and poorer ears remained the same.

Additional studies that might be relevant to the population of children with MBHL are those that have documented the effects of auditory deprivation in children with recurrent conductive hearing loss during periods of language development. Although all periods of language development are important, a sensitive period is defined as a time interval in which an organism is biologically prepared to acquire certain behaviors as long as there is a stimulating, supporting environment.<sup>15</sup> Hearing losses associated with otitis media with effusion (OME) can range from 15 to 55 dB HL but typically average 20 to 25 dB HL.<sup>16-18</sup> These losses might be transient or more chronic in nature. Collectively, prospective studies of children with recurrent OME suggest that mild hearing loss associated with OME in early life is associated with poorer extended high-frequency hearing sensitivity and atypical auditory brainstem pathway indices (elevated crossed, but not uncrossed, middle ear acoustic reflex thresholds, and delayed wave V auditory brainstem response [ABR] latencies<sup>19</sup>) at

school age but not psychoacoustic or speech-in-noise tasks. However, other studies have demonstrated compromised deficits in binaural auditory tasks such as binaural release from masking<sup>15,20</sup> and speech-in-noise listening.<sup>21,22</sup> In some cases, difficulties resolved following treatment for middle ear disease or an extended period of normal hearing after resolution of OME.<sup>23</sup>

### Binaural Advantages

The listening difficulties that children with UHL experience can be explained in part by the loss of binaural advantages. Binaural advantages include localization, binaural summation, the head-shadow effect and binaural release from masking. Localization difficulties on the horizontal plane have been experienced by infants and children with UHL and are well documented.<sup>24-26</sup> Localization is affected because individuals with UHL do not have the benefit of interaural time and intensity cues. Typically, when sound approaches from 1 direction, the interaural time difference and ongoing phase differences at the 2 ears allow the individual to determine from which direction the sound is coming. Phase differences provide cues for low frequency information (below 800 Hz) and the head-shadow effect (diffraction effect of the head) is more noticeable for frequencies above 1500 Hz.<sup>27</sup>

Localization provides individuals with a sense of security within their environment for the purposes of mobility, safety, and communication. It is possible that in some group interactions, a child could lose time trying to locate the speaker, thus having reduced attentional and visual cues, and may miss some of the intended message. This could be experienced in a day care or classroom setting where different students around the class contribute to a discussion. Ricketts and Tharpe<sup>28</sup> demonstrated that children with mild to severe bilateral sensorineural hearing losses in classroom settings were more likely than their normal hearing peers to localize to utterances made by classmates (31% and 18% of the time, respectively). Although these authors did not have a definitive explanation, it was hypothesized that this difference may have resulted from a need for increased visual information for enhancing speech perception or for monitoring the environment in this population.<sup>28</sup>

The difficulties that children with UHL experience understanding speech in noise may also occur, in part, because they receive reduced benefit of binaural

release from masking. Normal hearing in both ears helps listeners to detect and to recognize speech in noise. Studies have shown that hearing loss may affect binaural processing abilities, such as binaural release from masking, which can lead to greater difficulty understanding speech in noise.<sup>29,30</sup>

## Hearing Aid Technology Options for Children

### Current Practice Policies

*Identification and evaluation.* Current practice guidelines provide audiologists with recommendations that are relevant to the early identification and confirmation of hearing loss in infants and children.<sup>31,32</sup> Although our current screening technologies (eg, automated auditory brainstem response [AABR] and otoacoustic emission [OAE] testing) are effective at identifying moderate or greater degrees of hearing loss, a significant proportion of infants with milder degrees of hearing loss may be missed. Johnson et al<sup>8</sup> found that a high proportion of infants with later confirmed bilateral or unilateral mild permanent hearing loss were not identified (using a pass or refer criteria) by a 2-step, 2-technology hearing screening protocol (OAE followed by AABR testing). Although it is possible that some of these losses progressed or had onset after the newborn period, it is reasonable to assume that many of these were missed by the screen.

As our current electrophysiologic and behavioral techniques are not sensitive to some minimal degrees and configurations of hearing loss, children with MBHL or mild UHL are likely to be identified, to have their hearing loss confirmed, and to be considered for hearing technology after children with greater degrees of hearing loss (see Ross et al, in this issue of *Trends* for an in-depth discussion).

*Amplification selection and fitting.* The American Academy of Audiology (AAA) Pediatric Amplification Protocol<sup>33</sup> addressed fitting of amplification on children with MBHL and UHL in its Special Consideration section. "Children with minimal and mild hearing loss should be considered candidates for amplification and/or personal FM system or sound-field systems for use in school. Use of hearing aid amplification is indicated for some children with unilateral hearing losses. The decision to fit a child with unilateral hearing loss should be made on an individual basis, taking into consideration the child's or family's preference as well

as audiologic, developmental, communication, and educational factors” (pg 3). Although these guidelines provide the clinician with various factors to consider when fitting a child with UHL with amplification, they do not make specific recommendations. The literature supports the difficulties these children can encounter, but evidence does not yet exist to support amplification for all children with MBHL and UHL.

*Pediatric prescriptive procedures.* The AAA Pediatric Amplification Protocol recommends the use of probe measurements to verify hearing aid fittings. Target values for gain and output are determined by a prescriptive method such as the Desired Sensation Level Approach (DSL).<sup>34</sup> The presentation of several input levels is recommended to determine the real-ear-aided-response and to provide a direct measurement of the predicted levels of amplified speech. For children with minimal degrees of hearing loss, these measures will be critical to avoid overamplification. When considering fitting a child with MBHL or mild UHL, one should first determine the amount of gain that will be recommended via a prescriptive method such as Desired Sensation Level (i/o).<sup>34</sup> In babies, open fittings and venting may not be an option because of their small canal size. Once real-ear-to-coupler-differences are taken into account, the prescribed gain at each frequency may be negligible and not worth occluding the ear canal to provide what can result in only a few decibels of gain at each frequency. However, these measures, in addition to behavioral audiometric thresholds, should be reevaluated at each visit as the rapidly growing ear canals of infants and young children will effectively lower the sound pressure level at the tympanic membrane. Over time, the amount of gain needed to make speech audible may necessitate additional parent counseling and/or the use of amplification.

One should also consider the possibility that for some young children the treatment condition (ie, amplification) may not provide benefit beyond a no-treatment condition or, in fact, may be worse than a no-treatment condition. For example, the low-level noise floor that is inherent in hearing aids is typically not heard by those with greater degrees of hearing loss or is offset by the advantages of improved audibility.<sup>35,36</sup> Given that audition can be improved for those with MBHL or UHL by slightly increasing the speaker voice volume or by decreasing speaker-to-listener distance, the fitting of amplification may not be worthwhile for all children.

It should be noted that current prescriptive methods are specifically studied and designed for children with bilateral hearing loss. Although DSL [i/o] v5 provides targets for a monaural versus binaural fitting, it might not specifically address the needs of children with UHL. That is, we do not yet know if children with UHL prefer the gain generated by a prescriptive method designed for bilateral hearing loss. For example, is the provision of optimal access to speech sounds (via matching targets as prescribed by DSL) as critical for a child with UHL as it is for a child with bilateral hearing loss? Should audiologists make adjustments to gain characteristics for children with UHL based on subjective preference? These are questions not yet answered and require audiologists to use clinical judgment in the fitting of children with UHL. Although the literature does not yet support which prescriptive method should be used for children with UHL, it is reasonable to continue to provide the best possible access to speech sounds for the ear with hearing loss (written communication with M. Bagatto, November 2007). In some cases, the degree of hearing loss in the impaired ear might determine which type of amplification is most appropriate. That is, if the goal of amplification is to provide access to speech sounds on the impaired side, access simply may not be obtainable if the degree of hearing loss is too great. Furthermore, the amount of asymmetry in speech perception between the 2 ears may affect binaural word recognition abilities. If word recognition abilities in the impaired ear are poor by clinical judgment, a prolonged trial with a hearing aid may allow the audiologist to determine benefit.

## Hearing Technology Options

Multiple types of technology options are available for children with UHL and MBHL. Factors such as age, degree of hearing loss, and listening environments should be considered when selecting hearing technology. In addition, audiologists' decisions may be influenced by existing evidence supporting the benefit of specific technology options.

### Conventional Technology

*Ear-level hearing aids.* The use of conventional hearing aids for children with UHL has met with some success, although the evidence in this area is limited and based on subjective reports of benefit.<sup>6,37,38</sup> Davis et al<sup>37</sup> sent out 150 surveys to families of children



with either mild bilateral hearing loss or UHL and had a return rate of 40%. Of 27 children with UHL who were fit with amplification, 26% reported wearing it all of the time, 4% reported wearing it only in school, and 50% reported never wearing it. Of 36 children with mild hearing loss, 44% reported wearing it all of the time, 3% reported wearing it only in school, and 25% reported never wearing it. Parents reported the stigma associated with wearing a hearing aid and bullying as possible reasons their child never wore their hearing aid. Parents of children with mild bilateral and UHL were also asked to rate how difficult it was for their child to listen in quiet and noisy situations, either with or without a hearing aid. For both populations of children, there were reported differences in both quiet and noise between the groups who wore and who did not wear a hearing aid. That is, those who wore hearing aids were judged by their parents to have greater ease of listening in both quiet and noisy listening conditions.<sup>37</sup>

In a study of 31 children with UHL, Kiese-Himmel<sup>6</sup> reported that 81% of children with moderately severe or better UHL accepted the use of a hearing aid. However, when the UHL was severe or profound, parents reported very poor use of hearing aid or no use of hearing aid. Similarly, McKay<sup>38</sup> administered a questionnaire to parents of 20 children, ages 2 to 17 years with UHL who wore hearing aids. Parents were asked to rate how their children were performing currently as compared with how they were performing prior to the fitting of amplification. All of the children had a moderately severe degree of hearing loss or better. In all, 72% reported improved or greatly improved performance on questions involving different listening environments. Many of the listening-environment questions were adapted from the Children's Home Inventory of Listening Difficulties (CHILD).<sup>39</sup> When asked, "How does your child like his or her hearing aid?" none reported that their child "hated it," 20% reported "being ambivalent," and 75% reported "liked it" or "loved it." Additionally, 100% of parents were happy with their decision to fit their child, and 50% wished they had fit their child with a hearing aid sooner. Most of the children in this group were school aged. For the children who were under 3 years of age, ratings were less positive. That is, on questions of listening abilities since provision of amplification, parents chose "same" suggesting no detriment and no improvement. It is possible that these younger children had not yet exhibited some

of the listening difficulties that older children had in more challenging listening environments; therefore, the parents had not noticed changes in performance in the conditions queried. Parents of these younger children were still happy with their decision to obtain the hearing aids.

Preliminary findings from a study by McKay et al<sup>40</sup> designed to evaluate the perceived listening abilities of children with UHL suggest that a significant number of parents are selecting amplification for their children with UHL. A total of 243 patients, aged between 7 to 12 years, identified with permanent UHL over an 18-month period in the audiology clinic at The Children's Hospital of Philadelphia were mailed the CHILD<sup>39</sup> and a demographic questionnaire about hearing aid and/or use of frequency modulation (FM) and provision of special services in school. Of the 243, 53 returned the surveys and, of those, 17 (32%) reported using a hearing aid. However, after accounting for those with severe to profound UHL or anatomical contraindications for amplification, 46% of the total (eligible) number of children wore a hearing aid. Parents reported that 100% of children wore their hearing aids in school and that 59% wore their hearing aids outside the school. There was an association between hearing aid use and use of support services. Of the children who wore hearing aids, 71% also received some form of support services in school and 29% received no services. Interestingly, children who wore hearing aids scored significantly poorer on the CHILD questionnaire (by both parent and child response) than those who did not wear hearing aids. It should be noted that the CHILD queries listening situations outside of school and some children only wore their aids in school. The reasons for this finding warrant further study.

Finally, Kiese-Himmel et al<sup>41</sup> examined the acceptance of hearing aids over time in children with bilateral hearing loss and UHL ranging from mild to profound. They found that children with UHL wore their hearing aids less often than children with bilateral hearing loss. However, they found that this was true only after the children with UHL had worn their hearing aids for a period of 30 months. It should be noted that 50% of children with UHL in this study had profound loss in their affected ear. The decrease in usage over time may be attributed to children realizing that they can get many listening situations without the aid or may simply be because they obtained no usable benefit from amplification.

There are several hearing aid characteristics that need to be considered when fitting a child with MBHL and UHL. For children with MBHL or UHL hearing loss, some specific fitting decisions, such as the use of wide dynamic range compression (WDRC), will be automatic. The WDRC will automatically adjust the gain of the hearing aid based on the input insuring natural perception of loudness growth (eg, soft sounds including speech) remain soft, yet audible and loud sounds are perceived as loud but not uncomfortable.

The use of feedback cancellation circuitry may not be needed for children with moderate degrees of UHL or better. Unlike the gain recommended for a severe or profound hearing loss, the gain recommended for a mild to moderately severe hearing loss typically does not produce feedback for a child with a well-fitting earmold. However, one must consider situations that may still cause feedback (eg, wearing a hat, lying down). The use of more open fittings, multimicrophones, and directional microphones may be dictated by configuration of loss, age, and the child's ability to monitor his or her listening environment and to make appropriate changes when needed.

The use of directional microphones for children with hearing loss may be beneficial in some listening situations but may also be detrimental in others.<sup>28</sup> Children's limited experience with receptive speech, the importance of learning through overhearing, and their possible unwillingness to appropriately turn their head toward the desired sound source may all be potential limitations of directional benefit specific to the pediatric population.<sup>28</sup> Even if children are not able to orient their heads correctly, Ricketts<sup>42</sup> reported that when directional microphones are in the automatic mode, the appropriateness of switching is approximately 90%, and even if it is in the wrong mode 10% of the time, the child might still experience significant overall benefit. Although FM will provide the greatest signal-to-noise ratio, it may not always be available for all children. Therefore, Ricketts and Tharpe<sup>28</sup> suggested the use of a directional microphone for school-age children during desk-work time if FM is not available.

*Contralateral routing of signal hearing aids.* The contralateral routing of signal (CROS) hearing aid is considered as an option for individuals with UHL and unaidable (severe to profound) hearing in the impaired ear. A microphone on the impaired ear sends the signal via hard-wire or wireless technology to a

receiver on the normal hearing ear. For issues of retention, a behind-the-ear (BTE) receiver is often coupled with an open earmold or may also be in the form of an in-the-ear (ITE) receiver. When considering CROS amplification for children with UHL, clinicians should weigh the effect of partially occluding the normal hearing ear. In some adults using CROS amplification, improvements in localization were observed.<sup>43</sup> These improvements were thought to be the result of differences in sound quality between both ears. When the signal was perceived as sounding natural, it was thought to be arriving on the normal hearing side; when the signal was judged as sounding tinny, it was thought to arrive from the impaired side. These improvements in localization were not present in high levels of ambient noise. The CROS system may be useful in some situations, especially in cases where the speech signal originates on the side of the impaired ear. However, as a child's listening situation is dynamic, the intended sound source may originate from any location. The CROS amplification may not be beneficial in the classroom, where children are in assigned seating arrangements because of the introduction of noise to the normal hearing ear via the microphone on the impaired side.<sup>44</sup> If a child is not able to competently monitor his or her listening environment and to make judgments about when the CROS system may or may not be appropriate, this introduction of noise to the normal hearing ear may actually be detrimental. The CROS system should therefore not be considered as an option for young children.

*Frequency modulated systems.* The benefit of FM technology in children with MBHL and UHL has been well documented in the school-age population.<sup>44-47</sup> Increasing the signal-to-noise ratio is clearly an advantage for children in academic situations; for some children with MBHL and some degrees of UHL, it may be the only device option. A recent study by Tharpe et al<sup>45</sup> examined the speech perception benefits of various fitting configurations of an ear-level FM system by children with minimal to mild degrees of hearing loss (including some children with UHL). In addition, they examined the desirability of the various configurations as perceived by the children. As expected, these children demonstrated significantly better speech perception ability in noise (originating from various sources) when wearing any of the FM configurations as opposed to the unaided condition. Bilateral FM placement resulted in significantly better speech perception scores than monaural

placement in only 2 of the sound source locations (0° and 270° azimuth), suggesting that it is reasonable to have monaural FM fittings that leave 1 ear available (ie, unoccluded) for listening to speakers who are not using a microphone. Moreover, the overwhelming majority of children enrolled in this study liked wearing the ear-level FM device and opted to purchase the system at the end of the study. Although they were unable to state their reasons, the children who wanted to keep the FM systems wanted a monaural configuration.

Although ear-level FM provides the better signal-to-noise ratio as compared with sound-field options,<sup>48</sup> this choice of FM coupling may not always be the most practical based on the needs of the child. As is the case with personal amplification, choices for FM need to be made on an individual basis considering the environment in which the device will be used, age of the child, degree and configuration of hearing loss, and use of a hearing aid. If a child already has a mild-gain, BTE hearing aid, one may choose to couple an FM receiver to the hearing aid. Another option is to couple the FM to the unaided ear via an ear-level FM system. If an FM system is coupled with the normal hearing ear, the fitting must remain open to insure that the child has access to other sounds and to his or her fellow classmates. This is particularly important if the loss in the impaired ear is severe or profound. Personal and sound-field FM or infrared systems may also be a viable option, particularly for older children who wear in-the-ear hearing aids.

Studies, such as those conducted by the Mainstream Amplification Resource Room Study (MARRS) Project,<sup>49</sup> have demonstrated that classroom amplification systems benefit all children in the classroom and not just those with hearing loss, attention, or auditory processing disorders. Advantages of sound-field amplification systems are both qualitative and quantitative. In a summary of studies conducted in classrooms with sound-field amplification,<sup>50</sup> children were found to have increased attention, decreased discipline problems, reduced distractions, increased participation, and an overall increase in on-task behavior relative to children in classrooms without amplification. Furthermore, teachers were required to provide fewer verbal repetitions and redirections and had a decrease in vocal strain. The Trost Study<sup>51</sup> evaluated children in amplified and nonamplified classrooms over one academic school year. Children in first-grade amplified classrooms

scored 35% higher on the Dynamic Indicators of Early Literacy Skills tool and 21% higher on the Developmental Reading Assessment tool than children in nonamplified classrooms. On the basis of the positive findings of studies like these, some schools are electing to have all of their classrooms outfitted with sound-field FM or infrared units. Although these studies included children with normal hearing, not those with MBHL or UHL, it is reasonable to expect that children with hearing loss would receive equal benefit, if not more, from such arrangements.

One possible negative consequence to the installation of sound-field amplification systems in all classrooms is the belief that this will be sufficient for all children with hearing loss and that they will not need additional ear-level devices. Anderson and Goldstein<sup>48</sup> found that classroom amplification systems did not provide benefit beyond that of the children's personal hearing aids. In situations where there is a classroom amplification system in place, a trial with ear-level FM may be recommended. Functional auditory measures such as the Screening Instrument for Targeting Educational Risk<sup>52</sup> should be used to document results in both listening conditions.

McKay et al<sup>40</sup> found that in one group of children with UHL from 7 to 12 years of age, 53% used FM technology in school. Of the children who used FM, 18% used FM that was coupled with their hearing aid, 7% used ear-level FM on the normal hearing ear, 32% used a personal sound-field system (desktop unit), 39% used a classroom sound-field amplification system, and 4% did not report the type of FM used. In all, 36% of children in this group used FM technology with their hearing aids. As can be seen, most children were reported to use sound-field amplification systems, and it is not known if these systems already existed in the classroom and if the use of these systems affected choice or eligibility for ear-level FM.

There is no evidence to date to support whether FM is an appropriate choice for infants and toddlers with MBHL or UHL. However, given the documented listening difficulties of older children with UHL, one could surmise that infants could also benefit from an improved signal-to-noise ratio. Because a majority of what young children learn is through incidental learning, parents would need to be vigilant about their choice of when and when not to use FM. For example, appropriate times of FM use by a young child might include when placed in a stroller, car seat, or during instructional time in a day care or preschool environment.<sup>53</sup> As children approach

school age or if they are already receiving early intervention services, it is recommended that decisions about the use and type of FM system be coordinated with the child's educational audiologist and/or hearing support teacher. The educational audiologist or hearing support teacher might have additional pertinent information about the classroom setting and use of FM with other students that has to be considered.

### Nonconventional Hearing Technology

Currently, there are some hearing technologies that have been used in adults but have little empirical support for their use in the pediatric population. Two technologies that provide transcranial delivery of the signal via bone conduction from the impaired side to the normal cochlea are the bone-anchored hearing apparatus (BAHA) and the transcranial CROS.

**BAHA.** The BAHA was originally intended for individuals with conductive or mixed hearing loss. The BAHA is surgically implanted into the temporal bone. Because of anatomical issues of maturation, the Food and Drug Administration has only approved the use of the BAHA in children over 5 years of age.

Priwin et al<sup>54</sup> reviewed outcomes of 22 children, ages 6 to 17 years with bilateral and unilateral conductive hearing loss who were fit with the BAHA. In this study, children with conductive UHL fitted with the BAHA showed improvements in speech recognition abilities in the most adverse noisy conditions but no improvements in sound localization. Results of the Swedish version of the International Outcome Inventory for Hearing Aids, a questionnaire administered to the children in the study, suggested general satisfaction with fitting of the BAHA and a high degree of quality of life after being fitted.

The BAHA has also been marketed for individuals with severe to profound sensorineural UHL. Unlike conductive hearing loss, the delivery mode of sound in individuals with profound sensorineural UHL is solely transcranial and, as such, results cannot be compared with those obtained in studies on conductive hearing loss. There are various reports of BAHA fittings on adults with profound UHL.<sup>54-57</sup> These results ranged from no improvement in localization to improvement of speech in noise, improved performance compared with other device fittings, and subjective reports of benefit.

One common result shared by many adult studies is the subjective preference of the BAHA to traditional CROS amplification and improved speech-in-noise abilities when using the BAHA as compared with the traditional CROS.<sup>58-60</sup> However, improved recognition for either device over unaided conditions are normally minimal except in cases where the speech is directed to the aided ear and where the noise is from some other direction. Negative effects are often observed when the noise is coming from the aided side. In addition, benefit is often smaller or not present in conditions where the speech and noise come from the same direction or the speech is in front and the noise surrounds the listener.<sup>55,61</sup> Although the BAHA is available for children with severe-to-profound UHL, no studies to date have been reported on BAHA fittings with children with severe to profound hearing loss.

**Transcranial CROS.** The transcranial CROS fitting is achieved by providing a high-power ITE, completely-in-the-canal, or BTE hearing aid to the impaired side that will generate enough output to stimulate the contralateral cochlea. There are limited reports of benefit with this fitting in adults. Valente et al<sup>62</sup> studied 8 adults with unaidable sensorineural hearing loss in 1 ear (a result of acoustic neuroma) and normal hearing in the other ear. They compared a wireless CROS fitting to a transcranial CROS fitting for each patient. After a 60-day trial, 3 patients preferred a transcranial CROS, 4 patients preferred a wireless CROS, and 1 patient did not benefit from either system. Although the patients seemed homogeneous, the authors of this study concluded that no single recommendation could be made for this population. The patients who preferred the transcranial CROS reported a more natural sound and better localization relative to the wireless CROS. Patients also reported improved listening in noise with the transcranial CROS only when the signal originated on the side of the aid. Unlike children, adults can easily detect listening situations that may be adverse and can usually make accommodations such as changing their position or turning off their hearing aid. From evaluations of the patient diaries and questionnaires, Valente et al<sup>62</sup> found that all patients entered into the study wanting the transcranial CROS fitting to be successful. The patients cited that it would be easier and less expensive to have one hearing aid instead of two and that they would have greater ease leaving the normal hearing ear unoccluded (ie, on the telephone).



A Trans Ear is a unique type of transcranial amplification described by Valente et al<sup>43,63</sup> With this device, a BTE hearing aid is coupled with a small bone-conduction vibrator encased in an earmold worn in the poorer ear. This device is available with 2 programs for listening in quiet and in noise. Valente et al<sup>43</sup> initially evaluated 3 adult patients using the Trans Ear but were reportedly not able to achieve an appropriate amount of gain because of feedback issues. The manufacturer has reportedly made changes to the size of the bone vibrator based on these findings, and Valente<sup>63</sup> has subsequently reported improvements in the amount of achievable gain and comfort for adult patients. To the authors' knowledge, no other studies on the efficacy of this device have been reported to date.

As the BAHA and the transcranial CROS provide transcranial delivery of the signal in individuals with profound UHL, one could speculate that in adverse listening situations, the introduction of noise to the impaired ear, which is sent to the normal hearing ear, would have a similar effect on a child to that of a CROS aid.<sup>44</sup> Additionally, the use of a BAHA necessitates undergoing a surgical procedure. Although these devices appear to benefit some adults, more studies are needed on their use specific to pediatric populations before they are recommended for children with UHL.

*Validating children's functional auditory performance.* Audiologists are challenged to educate families regarding the effect of MBHL and UHL on their children. The effects may be subtle and difficult for families to observe. As such, the use of functional auditory assessments may help families during the decision-making process to determine whether they want to pursue hearing technology for their child. These measures allow the audiologist to determine which listening situations may give a child more difficulty and can serve to facilitate counseling and may open up discussions among the parent, audiologist, and child, when appropriate. In an informational booklet entitled *Incorporating Functional Auditory Measures into Pediatric Practice*,<sup>64</sup> specific functional auditory assessment measures are recommended based on age and degree of hearing loss, including minimal degrees of loss. As the clinic is only a snapshot of a child's everyday life, the use of functional auditory measures may give audiologists the information they need for appropriate child-specific recommendations.

## Other Management Considerations

On identifying a child with MBHL or UHL, audiologists and/or parents may not feel comfortable with immediate fitting of amplification. As discussed, more audiological testing may be needed to confirm degree, type and configuration of hearing loss or gain as prescribed by DSL may be too negligible during infancy to warrant amplification. Additionally, parents may choose to wait to determine if their child is experiencing any difficulty as the result of their hearing loss. During this watch-and-wait period, parents can be educated about how to help their young child at home, and if applicable, in their day care or preschool environment. During the first year of life, babies are likely to be in close proximity to their caregivers (eg, being held or fed), and during this time they have the advantage of a superior signal-to-noise ratio. Once a baby begins walking, the signal-to-noise ratio will be less optimal as increased distance and background noise may be factors.

Even if parents choose not to have their baby fit with a hearing aid immediately, they can be provided with information that will help them make their child's listening environment optimal. They should be aware of how to make their voices most audible and should always look at their baby when they are speaking. Parents should also try to minimize extraneous background noise when they are interacting with their baby. In the case of UHL, parents and caregivers should always be aware of the child's position in different listening environments. Examples might be, not to place a child with a right-sided UHL behind the driver's seat in the car or not to seat a child with their normal hearing ear facing a noise source such as a room air conditioner. As a child becomes more mobile through crawling or walking, the signal-to-noise ratio will become less optimal than it was during infancy because of greater speaker-listener difference. Children will likely hear their parents' voices from a distance (ie, another room) but may not understand the entire message.

## Conclusion

Children with MBHL and UHL are at risk for academic, speech-language, and social-emotional difficulties. Referral to early intervention, speech and language monitoring, and provision of resources to parents is recommended.<sup>32</sup> Amplification may also

be a good option for some children with MBHL or UHL, and FM should always be considered.<sup>33</sup> However, it should be noted that evidence does not yet exist to determine which children with MBHL or UHL will experience difficulties, and consequently which children will benefit from early intervention and early amplification. Until evidence is available to support the benefit of early amplification for children with MBHL or UHL, decisions should be made on a child-by-child basis and will ultimately be determined by a parent's choice to be proactive or to take a wait-and-see approach. More studies are needed to support the decisions made for young children with MBHL and UHL. In the interim, audiologists should regularly monitor hearing and communication development. Additionally, they should continue to educate parents and other caregivers on how to help give their child the best chance for success.

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