Audiologic Assessment for the Fitting of Hearing Instruments:
Big Challenges from Tiny Ears

Judith S. Gravel

Building a Sound Foundation

With the age of identification of hearing loss rapidly diminishing, pediatric audiologists are suddenly faced with the long-desired opportunity to provide hearing instruments to very young infants diagnosed with permanent childhood hearing loss (PCHL). Along with these exciting possibilities, however, come many sobering challenges. This chapter addresses the importance of the comprehensive audiologic assessment and the role of behavioral testing in the follow-up and management of infants and toddlers with PCHL. These fundamentals of pediatric practice are the foundation for the fitting of amplification to very young children that is safe, comfortable and highly effective.

The Pediatric Working Group on Amplification for Infants and Young Children (Bess et al. 1996) recommended that a young child with permanent bilateral hearing loss of 25 dB HL or greater in the 1000 to 4000 Hz range should be considered a candidate for amplification (see Appendix). This degree of PCHL was deemed to be potentially deleterious for the perception of acoustic speech features necessary for the development of typical aural/oral communication. The Pediatric Working Group also suggested that young children with unilateral hearing loss, hearing loss less than 25 dB HL, or those with rising or falling (high-frequency) hearing loss configurations at frequencies above 2000 Hz might also receive benefit from amplification technology (see Appendix).

In an adult, a mild degree of hearing loss (25 to 40 dB HL) would not necessarily result in a communication disability (depending on the acoustic characteristics of the listening environment). Nozza has suggested, however, that even in optimal (quiet) listening conditions, a minimal (20 to 25 dB HL) hearing loss is likely to be deleterious to an infant's ability to discriminate speech sounds (Nozza 1986; Nozza 1987; Nozza 1994; Nozza 2000). Therefore, the existence of any degree of PCHL in infancy could jeopardize the young child's acquisition of aural/oral language.

While recognizing the potential impact of hearing loss, clinicians have continuing concerns regarding the application of current amplification technology (e.g., wide dynamic range compression, programmable or digital instruments, FM) to infants and toddlers. Questions such as "What is the 'best' hearing instrument for a young first-time user?" and "What specific features are critical for optimum speech perception?" remain largely unaddressed. More important, there appears to be no systematic, widely accepted approach to the selection and evaluation of hearing instruments for very young listeners (Hedley-Williams, Tharpe, and Bess 1996).

Several considerations influence a clinician's decision regarding whether or not to recommend amplification. These include the availability and quality of habilitative and support services, the characteristics of the home and day-care environments, and the co-occurrence of other developmental disabilities. Not withstanding these and other variables, perhaps the single most important influence on an audiologist's decision to recommend amplification for a very young listener is the confidence of the clinician that the degree and configuration of the hearing loss have been accurately established.

The Test Battery Approach to Pediatric Audiologic Assessment

In order to make timely and appropriate management decisions, the audiologist is required to complete a comprehensive audiologic assessment of the infant at risk for PCHL. Use of a test battery for the evaluation of children's hearing is a fundamental tenet of pediatric audiology practice (Chase and Gravel 1996; Gravel and Hood 1998). Multiple current technologies allow the audiologist
to evaluate cochlear, middle ear, and neurologic integrity as well as higher-order auditory system function. The measures provide the pediatric audiologist with a unique view of hearing in its broadest sense.

In part, the test battery approach has developed from the classic paper of Jerger and Hayes (1976) describing the use of the cross-check principle in pediatric audiology. The test battery approach is an extension of the cross-check principle: agreement among all components (electrophysiologic and behavioral) of the test battery is necessary for the formulation of a clinical impression regarding the infant’s hearing status. In other words, each outcome is cross-checked with another. Included in the test battery is the case history as well as reports of family members regarding the infant’s auditory responsiveness. Lack of agreement among the results (including parent observations) mandates that the source of the discord be identified.

The components of the pediatric audiological test battery are presented in Table 1. Observe that the assessment procedures listed under each age category are identical; test order has been selected to enhance the efficiency of the protocol. Both electrophysiologic and behavioral procedures are considered integral components of the test battery in both age groups. One technology may serve as the primary method for threshold assessment, such as the frequency-specific auditory brainstem response (FS-ABR) in infants 4 months of age and younger. Note that even in this age group, behavioral observations of auditory responses are used to support or contradict the results obtained from the electrophysiologic measures. Again, it is unwise to assume that any procedure can be circumvented or eliminated from the test battery based on the outcome of any other test.

Several examples of the consequences of not adhering to this tenet of pediatric audiology practice are warranted.

Example 1: A clinician assumed no further assessments were necessary when the infant she was testing demonstrated threshold ABR recordings consistent with a severe hearing loss bilaterally in the presence of normal tympanograms. In this case, her assumption of cochlear hearing loss, however, was incorrect. Several important components of the test battery were not completed, the outcomes of which would have resulted in an entirely different clinical impression; specifically, neuro- (high-intensity clicks) ABR, evoked otoacoustic emissions (EOAEs), and acoustic reflex threshold assessment.

Clinicians have become increasingly aware of a complex auditory dysfunction in infants and young children termed auditory neuropathy (Berlin et al. 1997; Fabry 2000; Sininger et al. 1995; Starr et al. 1996; Stein et al. 1996). The disorder is characterized by highly atypical or absent ABR waveforms, the presence of the cochlear microphonic, absent acoustic reflexes, and robust EOAEs. Children with auditory neuropathy often exhibit some degree of hearing loss when assessed using audiometry and the configuration and degree are variable. These children usually have severe difficulties understanding speech. Conventional hearing instruments are generally not useful. However, FM systems may be of some benefit in certain listening situations (Fabry 2000).

By using only some components of the pediatric test battery, in this example the audiologist failed to recognize an infant with possible auditory neuropathy. The clinical

Table 1. Components of the comprehensive audiological test battery used for the assessment of infants and young children in two age groups (developmental age): 1 month to 4 months of age and 5-6 months to 24 months of age. The table shows the suggested sequence of audiological assessment procedures.

<table>
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<th>1 month to 4 months</th>
<th>5-6 months to 24 months</th>
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<td>Family’s Impressions &amp; Observations</td>
<td>Family’s Impressions &amp; Observations</td>
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<td>Evoked Otoacoustic Emissions</td>
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<td>Acoustic Immittance:</td>
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<td>Tympanometry &amp; Acoustic Reflex Thresholds (660 Hz)</td>
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<td>Auditory Brainstem Response (ABR)</td>
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<td>Low- and High-frequency thresholds (frequency-specific ABR) and Neuro-ABR (high intensity clicks)</td>
<td>Low- and High-frequency thresholds (frequency-specific ABR) and Neuro-ABR (high intensity clicks)</td>
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<td>Observation of Infant’s Auditory Responses in the Clinical Setting</td>
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impression of cochlear hearing loss based on the initially incomplete audiologic assessment resulted in the initiation of inappropriate and ineffective early management decisions.

**Example 2:** A clinician failed to administer acoustic immittance measures to the 4-month-old infant he was evaluating. The audiologist thought tympanometry and acoustic reflex threshold measures were invalid in very young infants. This baby had failed both newborn hearing screening and outpatient follow-up tests. The infant’s ABR thresholds were elevated, and EOAEs were absent. Unfortunately, a protocol for recording bone-conducted ABR thresholds was not in place at his facility (Stapells 1989). The baby’s mother reported, however, that her pediatrician had observed normal-appearing tympanic membranes using standard otoscopic examination at a recent visit. Based on the tests completed, the audiologist’s impression was of the existence of a moderate-severe cochlear hearing loss. The parent was counseled accordingly, and plans for early intervention (including amplification fitting) were discussed. Indeed, this infant had a conductive hearing loss secondary to otitis media with effusion (OME).

Once again in this case, critical components of the pediatric test battery were not completed: in particular, bone-conduction ABR and acoustic immittance measures. The former measure would have revealed the existence of an air-bone gap and the suggestion of normal thresholds for bone-conducted stimuli. In this case, acoustic immittance measures also would have been informative. Many clinicians consider acoustic immittance measures to be unreliable when used with young infants. Indeed, tympanograms of infants 7 months of age and younger derived using a conventional 220 Hz probe frequency have been reported to be invalid indicators of middle ear status (Paradise, Smith, and Bluestone 1976). The significance of tympanogram patterns obtained from healthy ears of young infants using higher-frequency probe tones remains in question (Margolis and Hunter 1998). However, in infants 4 months of age and younger, a flat (noncompliant) (susceptance) tympanogram obtained using a 660 Hz probe frequency was found to be related to the presence of middle ear effusion (Marchant et al. 1986). The probability of eliciting acoustic reflexes in infants under 4 months is also increased when a 660 Hz versus 220 Hz probe frequency is used (Marchant et al. 1986). Roush and his colleagues (1995) have provided quantitative normative values for tympanometric width (TW in daPa) and peak admittance (YTM in mmohs) obtained with a 220 Hz probe tone for infants and toddlers 6 months to 30 months of age. Acoustic immittance measurements should be considered important components of the pediatric test battery, but a high-frequency probe tone (660 Hz) appears to improve the sensitivity of tympanometry for the detection of middle ear effusion and for eliciting the acoustic reflex in very young babies.

**Example 3:** A 6-month-old infant was referred for ABR following a behavioral test that was consistent with a severe hearing loss. At the facility providing the ABR, the protocol was to begin the threshold search at low stimulus intensity levels and increase the level until reliable responses were obtained. The infant was noisy throughout the test session. However, the available recordings were considered to be consistent with normal ABR thresholds bilaterally. The mother continued to be concerned about the infant’s lack of response to sound and sought a second opinion at several centers. Audiologists were aware of the normal ABR finding before their behavioral assessment was begun. Resultant audiograms were consistent with normal hearing thresholds. Only tympanometry was completed at the time of the behavioral tests. The child’s lack of response to sound and language delay were attributed to a severe central auditory processing dysfunction. Behavioral audiometry at 4 years of age was reliable and consistent with severe hearing loss. Ipsilateral and contralateral acoustic reflexes were absent, EOAEs were absent, and reliable ABR thresholds were consistent with severe cochlear hearing loss and no apparent neurologic component.

In this case, audiologists completing the behavioral tests were biased by the ABR result. Equally important is that critical components (EOAEs, acoustic reflex threshold measures) of the pediatric test battery were not completed. Those measures would have been in conflict with the ABR and behavioral findings and would have alerted a clinician to the apparent clinical paradox.

**Example 4:** Following a reportedly reliable behavioral hearing test (using conditioned orienting response audiometry) and the finding of normal tympanograms, the mother of a 9-month-old was informed that her baby had normal hearing. After a year, the parent sought another opinion regarding the baby’s hearing status since the toddler had not developed first words and continued to display little behavioral response to sound. At the second clinical facility, air- and bone-conducted FS-ABR, neuro-ABR, EOAE, tympanometry, and acoustic reflex threshold measures were completed along with VRA. All tests were consistent with severe cochlear hearing loss bilaterally.
In examples 3 and 4, audiologists either failed to corroborate the ABR result with unbiased behavioral tests and other physiologic measures or failed to support the behavioral test results with electrophysiologic measures.

**Example 5:** A toddler who had not developed speech was referred for behavioral audiologic assessment. The mother reported variable responses to sound, lack of social interaction, and poor play skills. A moderate sloping hearing loss was detected; test reliability, however, was considered only fair. A repeat test was also judged to be consistent with a bilateral hearing loss. The child was fitted with a hearing instrument on a trial basis. The toddler displayed no functional gain when tested with the hearing instrument, and the mother reported the toddler’s responses to sound did not change in the aided condition. The child received FS-, neuro-ABR, EOAE, and behavioral testing at another facility at the pediatrician’s request. The results of the electrophysiologic measures were consistent with normal auditory sensitivity. Visual reinforcement audiometry was unreliable because the toddler was unable to learn the response contingency using either air- or bone-conducted test signals. The developmental and auditory response patterns the toddler displayed were explained by the subsequent diagnosis of autism. The hearing aid was removed, and the toddler was placed in an early intervention program for young children with pervasive developmental disorders.

All of these examples demonstrate the unfortunate consequences of failing to administer the complete pediatric test battery. In all cases there was parental concern over observed auditory responses. These observations were not in accord with the results obtained at preliminary audiologic assessments. In all cases, incorrect initial impressions of these young children’s hearing status were drawn. Consequently, valuable months and years of auditory input and appropriate management were lost. Most important, parents experienced anxiety and stress over the unexplained deficits in their child’s lack of communication development.

Final comments on the recommendation to use a complete pediatric test battery are warranted. Often the ABR is not considered necessary (particularly in older babies) when the behavioral tests are reliable, and EOAEs, acoustic reflex thresholds, and parental observations are all consistent with PCHL. However, our experiences suggest that ABR recordings completed during the initial stages of the comprehensive audiologic assessment later can serve as a valuable index of auditory system integrity. There are several reasons we have found the early ABR recordings of great value. Comparisons between early ABR recordings and ABR assessments later in time can serve as an objective index for determining a change in auditory sensitivity or in auditory system integrity. This is particularly useful at certain ages (for example, around 2 years) when reliable behavioral measures are sometimes difficult to complete. Valuable time for medical and auditory intervention is not wasted pending the availability of a reliable behavioral test. Further, having both electrophysiologic and behavioral measures that support the audiologist’s concern regarding a change in auditory status is a powerful basis for referral. Finally, we have also found the ABR useful in determining whether there are potential neurologic factors that may coexist with a sensory deficit.

Thus, all components of the test battery contribute valuable information to the comprehensive assessment of hearing in infants and toddlers. No one test is sufficient for this purpose; none of the measures is redundant (Gravel and Hood 1998).

**After the Comprehensive Audiologic Assessment—What Next?**

One main function of the audiologic evaluation is to delineate the type, degree, configuration, and symmetry of the hearing loss. Under ideal circumstances, however, the target age for fitting amplification for infants with PCHL occurs before the age at which reliable behavioral audiometric testing is feasible (Widen 1993; Wilson and Thompson 1984). Fortunately, threshold ABR recording techniques (e.g., Gravel and Hood 1998; Stapells 1989; Stapells 2000) can be used to estimate auditory sensitivity accurately (to within approximately 10 dB of behavioral audiometric thresholds) within the frequency region important for speech perception in infants and young children with normal hearing and hearing loss (Stapells, Gravel, and Martin 1995). As such, current ABR methods are invaluable for assessing auditory sensitivity in infants before 5 to 6 months (developmental age). Fortunately, hearing aid selection and fitting can begin with minimal audiometric information. Threshold estimates at low- and high-frequency regions (e.g., using 500 and 2000 Hz tones, or a low-frequency tone and clicks) obtained using the ABR are a sound foundation for the initial stages of amplification fitting (Stelmachowicz, Seewald, and Gorga 1998).

Close monitoring of the stability of an infant’s hearing loss in the early months and years of life is also an important function of the audiologic evaluation. Progressive hearing loss must be detected as soon as possible so that medical referrals can be made, families appropriately counseled, hearing instrument frequency-gain charac-
Behavioral Observation Audiometry

In their classic 1984 chapter, Wilson and Thompson suggested the following limitations to the use of BOA for pediatric audiometry. First, observers and testers involved in BOA are biased. The audiologist in the control room and the test assistant and parent in the test suite are aware when test signals are presented. Examiners (audiologist and test assistant) and sometimes the parent need to agree that a behavioral response occurred during the presentation of a stimulus. This is assumed to be an indication that the infant’s response was valid. Such agreement among observers is irrelevant, however, if all are aware of when a signal is presented. The test assistant or the parent might inadvertently cue the infant when a test signal is presented, particularly when stimulus levels are high. Moreover, clinicians anxious to see a response will likely observe one when they are aware of a stimulus presentation.

Second, BOA allows numerous nonspecific behaviors (e.g., limb movements, eye-widening, cessation of sucking, eye-shifts) to be used as response indicators. Very young infants, however, generally exhibit numerous motor behaviors that may or may not be associated with the presence of an audible sound. When many behaviors are acceptable responses, the probability of accepting false-positive responses is high.

Third, BOA is greatly influenced by the age and developmental level of the child. Clinicians usually rely on published (e.g., Northern and Downs 1984) levels (in dB HL) to determine whether or not an infant’s responses are considered normal. These normal response levels change with age (development) and vary as a function of stimulus type. Speech, music, broadband noises, and other complex signals are more likely to elicit a behavioral response from a young infant rather than the narrow bands of noise or tones that are most useful for audiometric purposes. Infants’ responses also tend to habituate rapidly; thus, when BOA is practiced, test stimuli are usually changed frequently with the hope that a new or novel sound will result in dishabituation.

Fourth, infant state (sleep or wakefulness) and the characteristics of the test environment influence BOA. It is unclear which state is best for eliciting unconditioned response behaviors. The presence of visual and auditory distractions (such as verbal exchanges between parent and testers) may impact outcome.

Finally, and most important, infants with normal hearing show wide variability in their response levels. Response variability is so great that differentiation of babies who hear normally from those with hearing loss cannot be accomplished with confidence. Indeed, the wide range of response variability among infants with nor-
ormal hearing is the greatest limitation of BOA for pediatric audiometry.

As discussed previously, observation of a young baby’s auditory response behaviors is considered an important component of the pediatric test battery. This is particularly true for infants too young or children too disabled for conditioned response procedures. Flexer and Gans (1987) describe a method for overcoming issues of observer bias in behavioral observation audiometry. However, while observation techniques are encouraged for the purpose of examining functional auditory abilities (e.g., sound awareness, localization/orienting activity), the use of traditional BOA for audiomteric purposes is discouraged (Diefendorf and Gravel 1996).

VRA—A Conditioned Response Procedure

Fortunately, beginning fairly early in life, visual reinforcement audiometry (VRA) becomes an extremely useful assessment technique. VRA can be used to establish hearing thresholds (not minimal response levels) using a standard psychophysical procedure (up-down staircase) and conventional audiometric stimuli such as frequency-modulated (FM) tones and narrow bands of noise. The foundation for VRA was laid by the work of Suzuki and Ogiba (1960). The term VRA was coined in a report by Liden and Kanikunen (1969), although the procedure these authors described was different from the practice of VRA today. The VRA procedure in wide clinical use was developed and examined empirically at the University of Washington, Seattle, by Wilson, Thompson, Moore, and their students (see Wilson and Thompson 1984 for a historical review). Studies have shown that VRA is a valid and reliable procedure for hearing assessment of infants and young children beginning at 5 to 6 months of developmental age through approximately 24 months (Widen 1993).

VRA is an operant discrimination procedure in that a behavior (a head turn) is contingent upon the presentation of an audible test signal. The operant behavior is increased by the provision of pleasurable (positive) reinforcement. A conditioned response procedure is extremely useful for the purpose of hearing assessment since audiometric test signals (as discussed previously) have little or no reinforcing value. The VRA procedure, however, does not rely on any intrinsic appeal of test stimuli for maintaining the behavioral response. The stimulus serves only to cue the infant that a behavioral response (in this case, a unidirectional head turn) will result in reinforcement (Diefendorf and Gravel 1996).

The availability of appealing, animated toy reinforcers is essential for the successful practice of VRA. Having more than one toy reinforcer in the display further increases the novelty of the reinforcement. The toy reinforcers should be completely out of the infant’s view except during periods of reinforcement for correct responding. Housing the toys in individual dark smoked Plexiglas boxes serves this purpose. The toys are only available for viewing when they are activated and the box illuminated. This increases the appeal of the reinforcement so that responding is maintained over repeated trials and also reduces the likelihood that infants will randomly look at a toy that is always visible. Locating the reinforcer display in close proximity to the loudspeaker used for shaping the headturn response greatly increases the likelihood that VRA will be successful (Primus 1992). Moreover, it is important that the reinforcers be located at 90 degrees to one side of the infant; a 45-degree placement is insufficient for observing the desired robust head-turn response. Efforts directed at optimizing the toy display used for visual reinforcement, as well as ensuring the reinforcement unit is correctly located in relationship to the infant within the test suite, will greatly facilitate the successful practice of VRA (Diefendorf and Gravel 1996).

Because VRA is reliable, it has become an important tool in pediatric audiometry. Low variability allows clinicians to differentiate among infants with normal hearing and those with varying degrees of hearing loss (mild to profound). In table 2, mean sound field thresholds are presented for frequencies from 500 to 4000 Hz for infants 5, 7, 10, and 12 months of age with known normal auditory sensitivity (based on ABR) and normal middle ear function (Gravel and Wallace 1998). Values are rounded to the nearest 5 dB, as are the standard deviations. The results support the use of VRA in the clinical setting for determining infants with normal hearing from those with hearing loss in the short term and over time. Others have demonstrated similar findings in infants with and without mild hearing loss associated with OME (Eilers, Widen, Urbano, Hudson, and Gonzales 1991; Gravel and Wallace 2000).

In monitoring children with PCHL, early thresholds obtained using VRA are comparable to those obtained with conditioned play audiometry in preschool (Diefendorf 1988; Diefendorf and Gravel 1996). For audiologists managing children with hearing loss from infancy through childhood, the reliability of VRA thresholds over time and with thresholds obtained using other test procedures at older ages is of great benefit in the clinical setting.
Developing a Clinical VRA Protocol

A sizable body of literature is available that is useful in the development of efficient clinical VRA protocols. These protocols should maximize response probability and use time and test trials wisely. For example, neither signal type (tones, narrow bands of noise) nor the starting intensity (30 versus 50 dB HL) has an effect on conditioning success or VRA response consistency. However, starting level (30 versus 50 dB HL) does influence both the false alarm rate and the test efficiency (time). In other words, it is not efficient to waste valuable trials by beginning testing at intensity levels well above the infant’s threshold. Rather, the goal is to zero in quickly on an optimum (lowest) start level for the initiation of the threshold search. Widen (1993) and Tharpe and Ashmead (1993) suggest that VRA is most efficient when no conditioning trials are used and the threshold search begins immediately after contingent responding has been demonstrated, after only two to three trials (but see Potential Pitfalls below). This is an important difference between clinical versus classical VRA procedure in that in the latter, there is a period of shaping of the head-turn response. During this pre-test period, the infant learns the contingent head turn response. The infant needs to meet a specific response criterion (head turn to a signal trial, no response to a control or silent test interval) before the actual threshold search is begun. If it can be assured (based on ABR results, for example) that the test signal used in the conditioning phase is above the infant’s hearing threshold, then such a response-shaping period could be incorporated into the clinical practice of VRA. Many times, however, clinicians have no prior information regarding the hearing status of the infant presenting for assessment. A conditioning period using a signal that was not audible could lead to confusion and the support (reinforcement) of false positive responding. In addition, it appears a more efficient use of trials not to include a traditional conditioning phase (Tharpe and Ashmead 1993; Widen 1993).

Every correct response (that is, a head turn in the presence of a stimulus) is reinforced using a 100% reinforcement schedule; later this can be reduced to achieve intermittent reinforcement (Primus and Thompson 1985). Stopping the threshold search after three response reversals (correct-miss-correct responses following the first miss on the initial descent) provides as accurate an estimate of hearing sensitivity as continuing the threshold search to six or more response reversals (Eilers, Miskiel, Ozdamar, Urbano, and Widen 1991; Eilers, Widen, Urbano, Hudson, and Gonzales 1991). Thus, requiring the infant to make more than three response reversals increases test time but provides no improvement in test accuracy.

A Suggested Clinical Protocol for VRA

Based on the body of literature referenced above, our clinical research laboratory and pediatric audiology clinic use the following VRA protocol for the assessment of infants. It is efficient and provides clinicians with a consistent approach to the behavioral audiologic assessment of young children.

With infants 5 months to 13 months of age, narrow bands of noise are used as test stimuli. Beginning at 14 months (after the first birthday), frequency-modulated (FM) tones are used for audiometric assessment. Assessment is begun with sound field presentations of the stimulus (500 Hz) at 30 dB HL. Infants with normal hearing will usually orient toward the novel sound (Thompson and Folsom 1984). If the baby orient toward the loudspeaker, the head turn is reinforced, and another stimulus at the same level is presented. A head turn is again reinforced, and the threshold search (initial descending staircase) is initiated. If no response occurs, after two presentations at 30 dB HL, signal level is increased in 20 dB step sizes until an orientation (head turn) toward the loudspeaker occurs. Having two responses at the same level is the start level for the threshold search. On the initial descent, the step size is 10 dB and remains 10 dB for the up-down threshold search procedure. (This 10 dB step size is used only in the initial audiologic assessment to rapidly gain information regarding an infant’s hearing sensitivity.) Threshold is calculated from the levels of the three response reversals following the first miss on the initial descent. Sound field thresholds are obtained across the frequency range from 500 through 4000 Hz.

Table 2. Average hearing threshold data in dB HL (SD) at 500, 1000, 2000, and 4000 Hz at 5, 7.5, 10, and 12 months of age. Data are from infants with normal tympanometry at all visits in the first year of life. Data are 40 and 49 babies at each age level. All babies received ABR at or before 2.5 months of age to ensure normal cochlear function. Results represent normative data for sound field thresholds using a four-frequency, nonsequential computer-mediated procedure (Optimized Hearing Test Algorithm, Intelligent Hearing Instruments, Miami, FL). Reprinted with permission from Gravel and Wallace 1998.

<table>
<thead>
<tr>
<th>Age in Months</th>
<th>Frequency 500 Hz</th>
<th>1000 Hz</th>
<th>2000 Hz</th>
<th>4000 Hz</th>
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<tr>
<td>5</td>
<td>20(15)</td>
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4000 Hz whenever possible. Test frequency order is 500 Hz, followed by 2000 Hz, 4000 Hz, and then 1000 Hz. When sound field thresholds suggest a hearing loss, unmasked bone conduction testing is completed next at the same four frequencies (or minimally, at 500 and 2000 Hz) to determine the existence of an air-bone gap.

In cases where there is no response to sound field stimuli (at 80 dB HL maximum intensity), a bone-conducted signal (narrow band of noise at 250 or 500 Hz that is intense enough to be felt) is used to teach the infant the head-turn response using a classical conditioning approach. That is, the signal is presented via the bone oscillator placed on the mastoid closest to the reinforce display. The reinforcer is activated upon the presentation of the stimulus, and the infant is guided to look toward the reinforcer if necessary. When the contingent (anticipatory) head turn is established, thresholds for bone-conducted stimuli are obtained. Classical shaping of the head-turn response is a justifiable approach under these circumstances because the bone-conducted test stimulus is tactilie salient even if it is not audible.

Next, insert earphones are used to determine thresholds in each ear using the same order of test frequencies. Insert earphones are preferred over conventional supraaural earphones because they are lightweight, do not inhibit the head-turn response, and provide good interaural attenuation in the case of asymmetrical hearing loss. Thresholds achieved with insert earphones are useful in the prescriptive hearing aid selection procedure (see below). The ear closest to the visual reinforcer is tested first unless contraindicated by other test data. This facilitates the head turn toward the toy display. When the ear farthest from the visual reinforcer display is tested, the infant may turn toward the side opposite to the reinforcer display. In this circumstance, the visual reinforcer is activated, and the infant usually turns immediately to view the toy. If not, the parent prompts the response. The infant learns the location of the reinforcement has not changed and from that point turns automatically to the side of the reinforcement. The threshold search procedure for obtaining individual ear thresholds is identical to that described above for sound field assessment. Often we test 500 Hz and 2000 Hz in each ear, and then if the infant is still under good stimulus control (exhibiting contingent response behaviors), remaining frequencies (4000 and 1000 Hz) are assessed.

In later audiologic assessments of the infant with confirmed hearing loss, the step size is reduced to 5 dB. More than one test session may be necessary in order for the audiologist to fully delineate the audiogram in each ear. Intervention should not be delayed, however, pending the availability of a complete audiogram.

Conditioned Orienting Response (COR)
Audiometry Is Not VRA

A comment is appropriate here regarding the often synonymous use of the terms VRA and COR audiometry. COR is not the same procedure as VRA, and so the terms are not interchangeable. In COR, head orientation to signals delivered from loudspeakers located to the right and left sides of the infant is the desired response. Reinforcement is provided when the infant orients toward the appropriate loudspeaker. In COR, the infant is asked to make two determinations: signal detection and signal location. This two-stage process for a threshold search procedure may lead to higher estimates of hearing sensitivity than would be obtained if only a single discrimination was required as in VRA. Moreover, COR audiometry is usually conducted as only a sound field procedure. Therefore, it is unwise to suggest that head turns toward the right and left loudspeakers are indicative of symmetrical hearing thresholds (either normal or impaired).

VRA is a simple discrimination procedure (presence-absence of a test signal). The head turn serves merely as a convenient and developmentally appropriate behavioral response indicator. Initially, the headturn is a convenient response indicator because the infant will usually turn and look toward the source of a novel sound. This natural behavioral response facilitates the clinician’s shaping a contingent head turn for VRA assessment. Regardless of the transducer (loudspeaker, bone oscillator, earphone) or the ear to which the signal is presented, the behavioral head turn response is the same: in one direction only toward a single reinforcer display located at 90 degrees to one side of the infant.

Potential Pitfalls of VRA

An invalid test result due to false positive responding is a distinct possibility when VRA is used for hearing assessment (refer to examples 3 and 4 above, and Berlin and Hood 1993). Nozza (1999) recently remarked, “It is easy to teach an infant the head turn. The hard part is teaching the baby not to turn.” Nozza’s (1999) comment was intended to stress that false positive responses could invalidate a threshold measure unless the clinician is assured that the infant is making contingent responses. Thus, he advocates for a period of conditioning before the threshold search to ensure that the infant is making correct responses to both stimulus and control trial intervals.
Control trials must always be incorporated in the VRA protocol, and ideally, a record of responses to each trial type should be maintained (Gravel 1992). High rates of false alarms (head turns when no test signal is present) indicate that the test is unreliable and should not be considered a valid estimate of an infant’s hearing status. False alarm rates of up to 30% have been shown not to affect thresholds (Eilers, Miskiel, Ozdamar, Urbano, and Widen 1991; Eilers, Widen, Urbano, Hudson, and Gonzales 1991). A false alarm rate exceeding 45% is indicative of an unreliable test in our laboratory, and the test is discarded (Gravel and Wallace in press, 2000). A specific false alarm rate that is unacceptable for clinical purposes, however, has not been determined empirically (Eilers, Miskiel, Ozdamar, Urbano, and Widen 1991; Eilers, Widen, Urbano, Hudson, and Gonzales 1991).

When a test session is considered unreliable, the infant is given a short break. Following the rest interval, an attempt is made to establish contingent responding by increasing the number of unrewarded control trials, increasing the intertrial interval, and changing the distracter (centering) toy for one of greater interest.

Sources of observer bias should be identified and reduced or eliminated. Test assistants and parents should be masked or use earplugs to reduce a source of observer bias. At our facility, we use one person (one audiologist) to test infants and believe it is an efficient means of carrying out VRA in the clinical setting. The limitation of a single tester is that there is an increased risk for examiner bias. However, two examiners who are aware of the type of trial (signal versus control) present an equally biased situation. The audiologist working alone must be constantly vigilant that bias is not influencing the test results and that false alarms are invalidating the test results.

Computer-Assisted Assessment

A way of eliminating tester bias while allowing a single audiologist to complete VRA is through the use of computer-assisted test procedure. Such a method incorporates control-trial intervals. On any given trial, the computer determines whether a signal or control condition is delivered based on a fixed probability of occurrence. The computer maintains a record of the infant’s responses during signal and control trials. Computer procedures can be made efficient by interleaving test frequencies, and probe trials (higher-level signals) provide a means of examining an infant’s attention and motivation during the test session (Bernstein and Gravel 1990; Eilers, Miskiel, Ozdamar, Urbano, and Widen 1991; Eilers, Widen, Urbano, Hudson, and Gonzales 1991).

A computer-assisted VRA test procedure is now commercially available (Intelligent VRA: Intelligent Hearing Systems, Miami, FL). Three test options are included, one for screening (Classification of Audiograms by Sequential Testing: CAST) and two assessment procedures (the Optimized Hearing Test Algorithm: OHTA, and a single frequency 5-up, 5-down procedure). The audiologist located in the exam room with the infant and parent communicates with the computer through a four-button hand-held response box. The audiologist is in complete control of all aspects of the evaluation. After bringing the infant to the midline position with a distracter toy, the audiologist signals the computer (via one button) that the infant is ready for a trial. If a headturn occurs during the trial interval (indicated by a small light that illuminates on the response box during the interval), the audiologist signals the computer (via a second button). If the response was correct (head turn to trial containing a test signal), the computer delivers the visual reinforcement. Buttons on the hand-held response box also allow the audiologist to abort a trial (signal the computer to ignore a response) and to pause the test session. A light indicates when the threshold search is complete. The audiologist and parent wear earphones and listen to music as a masker or use earplugs to reduce observer bias although the former is preferred.

The OHTA procedure is very useful for clinical purposes since it uses an efficient nonsequential four-frequency test algorithm to determine an infant’s audiogram (500 to 4000 Hz) in a single test run. All aspects of the procedure can be controlled (e.g., the response interval, duration of reinforcement, starting level, and stopping rule). A record of the infant’s responses during the session is available. The record chronicles the infant’s response to each trial type (signal, control, or probe), across the session as a whole, and for each test frequency. From the trial record and the summary data, the audiologist determines whether or not to accept the thresholds as valid. The decision is based on the percentage of correct responses to control trials (no head turn during a silent test interval) and the percentage of responses to probe-trial intervals. Thus, false alarm rate and the infant’s attention and motivation across the test session are quantified. Because the infant’s response behavior is documented, judgments regarding reliability of the test session are objective rather than subjective impressions. The response record also allows the audiologist to examine segments of the test run and determine whether during portions of the session the infant was
making contingent responses and was motivated versus other segments when random head turning increased or attention for the task waned. This type of computer-assisted procedure helps prevent the potential VRA pitfalls previously discussed.

**VRA and the Fitting of Hearing Instruments**

The VRA procedure for determining thresholds is especially useful for establishing targets for prescriptive amplification fitting. Determining the prescriptive targets for selecting the frequency-gain characteristics of the infant’s hearing aid is based on threshold data (Seewald et al. 1996). Thresholds at octave and half-octave intervals in each ear across the speech-frequency range (250 to 6000 Hz) are desirable. As suggested above, a 5 dB step size rather than 10 dB (as was used in the initial assessment) is used in the up-down staircase procedure. The smaller step size improves the sensitivity of VRA for monitoring hearing and for amplification fitting purposes. Obtaining a complete audiogram by “filling in” missing threshold values for each ear across the speech-frequency range is usually achieved over several follow-up visits.

Ideally, the values used in a prescriptive procedure to develop amplification targets should closely approximate the actual sound pressure level at the infant’s eardrum that was required to reach threshold as a function of frequency. Therefore, behavioral thresholds obtained using insert earphones will represent the actual threshold sound pressure levels better than thresholds obtained with conventional supra-aural earphones.

Because the volume of an infant’s closed ear canal is significantly smaller than an adult’s, as well as from that of a conventional 2cc coupler, the DSL has age-specific correction factors that are used to estimate the infant’s actual threshold in dB SPL. However, use of correction factors (based on group or average data) is less desirable than use of values that characterize the infant’s own ear. Thus, Seewald and his colleagues (Moodie, Seewald, and Sinclair 1994; Seewald et al. 1996) have described the measurement of the real-ear-to-coupler difference (RECD). The RECD values along with the infant’s thresholds obtained using insert earphones are then used in the calculations of the desired sensation level (DSL) method (Seewald et al. 1996) amplification targets (see Moodie et al. 1994; Moodie et al. 2000).

A way of further refining threshold values for use in the DSL prescriptive hearing aid fitting procedure is to use the infant’s own earmold to deliver test signals during VRA assessment. For this purpose, the nub of the insert earphone is inserted into the child’s earmold tubing (figure 1). Behavioral thresholds are then determined using VRA with test signals delivered via the insert earphone coupled to the infant’s earmold. The threshold values obtained will reflect the acoustic shaping imposed by the earmold characteristics (insertion depth, venting, and high- and low-frequency roll-off) when coupled to the infant’s ear. If only limited threshold values can be determined, it is recommended that a low (e.g., 500 Hz) and high (e.g., 4000 Hz) threshold be established in each ear.

When the infant’s RECDs (also measured using the same earmold) are applied to the VRA earmold-determined thresholds (EDTs), the result is the most accurate estimate possible of the SPL that will be required to achieve the DSL targets for that infant. Since the EDTs reflect an earmold coupling arrangement, the values are not comparable to thresholds obtained using a conventional insert earphone and foam tip. Each time the infant’s earmold is changed, EDTs should be reassessed (as are RECD values) with the new mold so that the frequency-gain and output target values can be modified as necessary (see Moodie et al. 2000).

**An Assessment and Management Model for Use in the First Year of Life**

A rigorous follow-up schedule for infants identified with PCHL should be adopted. The Pediatric Working Group (Bess et al. 1996, see Appendix) recommended that children fit with hearing aids should be seen by the audiologist every three months for follow-up during the first two years of amplification use. The group recommended that follow-up should include behavioral threshold tests (when age permits) and tests of middle ear function. More aggressive follow-up was called for when middle ear problems were detected so that prompt medical referral could be made and changes in amplification frequency-gain characteristics completed whenever necessary.

Figure 2 presents an idealized and somewhat more rigorous plan for the assessment and management of an infant with PCHL during the first year of life. The model assumes the initial identification of the hearing loss occurred during the neonatal period as a result of a newborn hearing screening. The model takes the audiologist through the schedule for the initial comprehensive audiological assessment (test battery completed within the first few months), the initial selection and fitting of hearing aids, enrollment in an early intervention program, and the subsequent monitoring of hearing status and refinement.
of the hearing aid fitting. Each infant is unique, and admittedly, each baby will have different needs, home and medical circumstances that will influence the audiologist’s decisions and the family’s ability to accept the proposed time course. It is hoped, however, that this model might assist clinicians in setting some goals for timely assessment, hearing aid fitting, and management of an infant with PCHL in the first year of life. The model is in keeping with current research that suggests intervention initiated within the first six months of life results in better receptive and expressive language than intervention begun after that age (Yoshinaga-Itano et al. 1998). It may be useful to provide a version of such a timeline to parents in order to inform them about what to expect in audiologic services during this important time period.

Summary

Audiometric assessment of infants identified as at risk for PCHL requires completion of a comprehensive evaluation using a battery of current test procedures. Following confirmation of PCHL, the long-term management of the infant includes detailed threshold assessment, monitoring hearing loss stability, and the fitting and refinement of amplification technology. All of these important responsibilities of the pediatric audiologist should be undertaken using valid and reliable assessment and management techniques. The VRA procedure is useful for these purposes.

Optimizing VRA for routine clinical use has significant advantages for the practice of pediatric audiology. However, important considerations for implementing the technique successfully include the need to reduce observer bias and to quantify the rate of false positive responses. Controlling both variables (through stringent manual VRA protocols or computer-assisted test procedures) is critical for ensuring the reliability and validity of threshold measures.

As suggested by the Pediatric Working Group (Bess et al. 1996, see Appendix), it is the responsibility of any facility engaged in pediatric audiological assessment and management to have current technology available, as well as professionals qualified and experienced to administer the measures and interpret test results. When one or more technologies or methods are not available, or when professionals lack expertise with particular measures, facilities should enter into consortia arrangements with centers that are able to provide the required services. Without current technology or viable agreements between centers, the practice of pediatric audiology should be discontinued.

When audiologists use sound strategies and thoughtfully apply current clinical methods for assessment and management purposes, they can approach with enthusiasm and confidence the many challenges presented by the tiny ears of infants who have PCHL.

References


## Figure 2

Proposed model for the audiologic assessment and management of an infant in the first year of life. Assessments, interventions, and services are depicted according to age of the infant in months (m). Generally, the left side of the timeline indicates audiologic services, and the right side indicates management and early habilitation visits. (FS-ABR: frequency-specific auditory brainstem response; EOAE: evoked otoacoustic emission; AC: air conduction; BC: bone conduction; mold-to-insert coupling: personal earmold coupled to the insert earphone for earmold determined threshold [EDT] testing; RECD: real-ear-to-coupler difference; HA: hearing aid; tym: tympanograms; ENT: ear, nose, and throat; EI: early intervention.)

<table>
<thead>
<tr>
<th>Age (m)</th>
<th>Services and Interventions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1m</td>
<td>Counseling</td>
</tr>
<tr>
<td>2m</td>
<td>Counseling; medical/ENT referral</td>
</tr>
<tr>
<td></td>
<td>Begin processes for HA procurement</td>
</tr>
<tr>
<td>3m</td>
<td>Mold impressions, EI Program</td>
</tr>
<tr>
<td>4m</td>
<td>HA Fitting</td>
</tr>
<tr>
<td>5m</td>
<td>HA Check &amp; (molds)</td>
</tr>
<tr>
<td></td>
<td>Review habilitation, milestones</td>
</tr>
<tr>
<td>6m</td>
<td>Behavioral &amp; tym (with EDT)</td>
</tr>
<tr>
<td>7m</td>
<td>Behavioral &amp; tym (with EDT)</td>
</tr>
<tr>
<td></td>
<td>RECD, HA modification, (molds)</td>
</tr>
<tr>
<td></td>
<td>Review habilitation, milestones</td>
</tr>
<tr>
<td>9m</td>
<td>Behavioral &amp; tym (with EDT)</td>
</tr>
<tr>
<td></td>
<td>RECD, HA modification, (molds)</td>
</tr>
<tr>
<td></td>
<td>Review habilitation, milestones</td>
</tr>
<tr>
<td>10m</td>
<td>Behavioral &amp; tym (with EDT)</td>
</tr>
<tr>
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<td>Behavioral &amp; tym (with EDT)</td>
</tr>
<tr>
<td></td>
<td>Validation measures, milestones</td>
</tr>
<tr>
<td>12m</td>
<td>Bed habilitation goals</td>
</tr>
</tbody>
</table>


