Chapter 5
Assessment of the Young Pediatric Patient

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The assessment and habilitation processes are of equal importance and need to occur for infants and young children with hearing loss within the first few months of life to maximize optimal outcome for a child. These two processes for children start off sequentially but occur simultaneously as more information is obtained about their hearing loss. The management process, including appropriate amplification and habilitation, is dependent on having a reliable definition of the child's hearing loss. Complete audiological information is necessary before the amplification fitting process can be completed, but reliable estimates at enough frequencies to fit a hearing aid can be used to initiate the amplification and habilitation process. Refinements and adjustments of a hearing aid fitting can be made as more and more precise information is obtained. Habilitation should not be delayed when only partial information is available, and valuable time should not be wasted waiting for complete information. This chapter will focus on assessing young infants and children, so that timely management can be initiated. The methods used for assessment vary as a function of age as the child acquires different skills and, therefore, capabilities for participation in the evaluation.

This concept of audiologic diagnoses and management as a process in the young child needs to be conveyed to the parents, who do not understand that the process often goes on for many years. Multiple visits are needed in order to define the exact configuration, degree, and nature of the hearing loss; monitor for possible changes; and alter management strategies as the child's auditory skills develop. Setting parental expectations early in the process will help them in their planning for their child. In addition, audiologists who provide services to children need to plan for this and offer appropriately long appointments so as to be able to complete assessments. Flexibility for different appointment options is essential to accommodate the child's and family's schedule.

Both behavioral and physiologic tests are used in the audiologic assessment of the very young pediatric patient. Behavioral tests are usually thought of as subjective, and physiologic tests are thought of as objective because of their reliance or nonreliance on patient participation, respectively. The electrophysiologic test findings (e.g., auditory brainstem response [ABR]) often predominate in decision-making about the management of the very young child with a hearing loss, as they are not capable of the full participation that is necessary for behavioral testing. For older children, generally, the behavioral audiologic findings—with or without ABR supporting data—are used to determine management of the hearing loss. Electrophysiologic and behavioral tests, however, provide information on different aspects of the child's auditory function and cannot serve as perfect substitutes for each other. Hearing thresholds do not match exactly when obtained using these different methods.

What follows are brief descriptions of the behavioral and electrophysiologic tests that are appropriate for the young pediatric patient. Typically, assessment protocols change with developmental age. Six months developmental age is typically when children switch from needing physiologic testing as the primary means of estimating thresholds to behavioral means of assessing thresholds. It should be highlighted here that behavioral audiologic testing of the young child can yield reliable results if proper procedures are followed during the test session.

Audiologic Assessment of the 0 to 6 Month Old

For children referred from newborn hearing screening programs, the typical protocol is to obtain a diagnostic audiologic evaluation after two failed screens. The exception to this are babies in the neonatal intensive care unit (NICU) who are referred for diagnostic testing after one failed screen.

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Auditory Brainstem Response (ABR)

When the child is seen for the diagnostic audiologic evaluation, the ABR is typically the primary evaluation method, but not in isolation of other tests. The ABR alone does not provide sufficient information but is essential for making proper decisions about management (American Speech-Language-Hearing Association, 2004). The other necessary components of evaluation for the young child are the case history, acoustic immittance testing, and otoacoustic emissions.

The use of the ABR to construct the audiogram has some limitations, although the benefits far outweigh the limitations. The major limitation is the choice of stimuli available that can be used to elicit the evoked response. Synchronous neural firing of multiple neurons is essential to record an ABR. The best stimulus to elicit a response is a rapid or abrupt onset stimulus, such as a click that stimulates a broad area of the basilar membrane (the structure within the cochlea that houses the sensory cells for hearing and that, when stimulated, activates the auditory nerve) and therefore generates synchronous neural discharge in a large number of neurons. The ABR to click stimuli will provide an overall assessment of the integrity of the auditory pathway and provide a basis on which to start investigating thresholds at specific frequencies.

Responses to click stimuli have been found to correlate best with audiometric findings in the higher frequency range from about 1000-4000 Hz (Coats & Martin, 1977; Gorga, Reiland, & Beauchaine, 1985; Gorga, Worthington, Reiland, Beauchaine, & Goldgar, 1985; Møller & Blegvad, 1976; Stapells, 1989). Since the click stimulus contains energy in a broad frequency range, the responses obtained are not considered to be from any one frequency (i.e., is not frequency specific). Responses obtained to click stimuli cannot detect impairments at specific frequencies. Use of this stimulus alone can either underestimate or miss a hearing loss at a particular frequency or

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frequencies depending on the degree and configuration of the hearing loss (Balfour, Pillion, & Gaskin, 1998; Stapells & Oates, 1997). While the use of age-appropriate, latency-intensity functions together with the threshold search will help to identify impairments, exact quantification of the impairment at each frequency cannot be done using the click stimulus. Frequency-specific or tonal stimuli must be used to determine response levels at individual frequencies.

A newer stimulus—a chirp—is being used in some screening and diagnostic ABR and ASSR equipment. The chirp stimulus shifts the frequency components of the click stimulus by presenting the low frequencies before the higher frequencies. The advantage of this is that the response will contain more low-frequency information than is obtained using a click stimulus. The resulting response is of higher amplitude given the addition of the lower frequencies. Data on the use of this stimulus at this time are just emerging in infants for screening and diagnostic testing.

The stimulus commonly used to obtain frequency-specific information is a brief duration tone burst referred to as a "tone pip." Fairly good synchronous neural firing can occur when using this stimulus. The tradeoff in becoming frequency-specific—or tonal by increasing the rise time of the stimulus—is the reduction of synchronous neural discharge. The goal is to achieve a balance of tonality with enough synchronous neural firing to elicit a response. It is necessary to maintain a fast enough rise time to elicit a response yet reduce the acoustic splatter, which occurs with rapid rise time (short duration stimuli), to frequencies above and below the nominal frequency of the stimulus. Producing a frequency-specific stimulus without significant contribution from other frequencies can best be achieved by using gating or stimulus shaping envelopes, such as Blackman functions (Gorga & Thornton, 1980). There is some debate whether the difference in stimulus spectrum when using these two gating functions equates into difference

Table 1
Suggested ABR Test Protocol

Stimulus	Setting
Filter	30- 3000Hz bandpass filter
Rate	Approximately 20/sec for click [remember to use an odd integer number (e.g., 17.1, 21.3, etc.)] and approximately 30/sec for tone bursts (e.g., 33.5, 31.7/sec)
Notch filter	Off
Amplification	100,000
Electrode array	High forehead, earlobe, and low forehead
Number of sweeps	1000-2000 for clicks; 2000-4000 for tone bursts (closer to threshold, more sweeps are needed)
Time window	20 msec (15 at the minimum for higher frequencies)
Transducer	Insert earphones, unless malformations do not allow for their use
Starting intensity	40 dB, unless strong suspicion of severe hearing loss is present
Number of channels	2

in the ability to predict thresholds at specific frequencies (Gorga, Kaminski, Beauchaines, & Jesteadt, 1988; Stapells & Oates, 1997). While producing a stimulus that does not have contributions from other frequencies is important, it will not ensure a place-specific region of excitation on the basilar membrane. As the intensity level of the stimulus is increased beyond 70 dB SPL, there is a physiologically upward spread of excitation on the basilar membrane (Pickles, 1986). Spread of energy to frequencies with better hearing will often result in an underestimation of threshold level.

There is not universal agreement that ABR testing should start with a click stimulus. Some believe that starting with the click will give an overall estimate of quality of response. Should there not be clear identifiable waveforms, the click can help to assess whether any cochlear response can be obtained (i.e., cochlear microphonic). The click can be thought of as similar to the speech recognition threshold (SRT). The SRT tells us very little of overall hearing; yet it provides a starting point for us to know

what degree of loss (in some frequencies) might be present. While a click ABR does not tell us much about thresholds across the frequency range, it allows us to determine a starting point for the tone bursts and provides an assessment of quality of response. The ABR to tonal stimuli does not produce the high-quality response that we see with the click. Knowing the type of response that an ideal stimulus produces for the ABR helps when evaluating the ABR to tone bursts. Others believe the way to obtain frequency-specific estimation of the audiogram is to start with a tone burst that produces the most click-like response (i.e., 2-4 kHz). The rationale for this approach is that time is saved by not obtaining responses to a click stimuli. The click ABR would only be done in cases where there is no response and a need to further probe the nature of the hearing loss.

Responses to both air- and bone-conducted stimuli should be obtained to assess presence or absence of air-bone gaps. ABRs in infants as young as the newborn have been shown to provide reliable estimates of pure tone thresholds for both air- and bone-conduction stimulation (Cone-Wesson & Ramirez, 1997; Sininger, Abdala, & Cone-Wesson, 1997; Stevens, Boul, Lear, Parker, Ashall-Kelly, & Gratton, 2013). While there are intensity output limitations in bone-conduction testing, it often helps to confirm the type of auditory impairment.

There are differences in the physiologic properties of adult and neonate skulls, resulting in differences in the transmission of energy between air- and bone-conducted signals. These physiologic differences result in the effective intensity of a bone-conducted signal for neonates being greater than for adults (Cone-

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> The characteristics of the infant's skull result in a more intense stimulus at the cochlea relative to adults, resulting in lower thresholds, generally shorter latencies, and larger amplitudes that are frequency dependent.

Wesson & Ramirez 1997; Foxe & Stapells, 1993; Stuart, Yang, & Stenstrom, 1990; Stuart, Yang, & Green, 1994).

Adult-infant differences in bone-conduction, tone-burst thresholds are found at different frequencies. At 500 Hz, studies show infants have lower bone-conduction ABR thresholds than adults, but at 2000 Hz, adults have lower thresholds than infants (Foxe & Stapells, 1993; Nousak & Stapells, 1992; Stapells & Ruben, 1989). Adult-infant differences in latencies show wave V latencies are longer in adults compared to infants for bone-conduction compared to air-conducted tone burst stimuli (Gorga et al., 1993). Differences also have been found between air- and bone-conduction latencies for infants to click stimuli, showing shorter ABR latencies for bone conduction than for air conduction (Hooks & Weber, 1984; Yang, Rupert, & Moushegian, 1987). Vander Werff, Prieve, and Georgantas (2009) found there are frequency-dependent differences in latencies and intensity level between air- and bone-conducted tone-burst ABR responses in infants (Foxe & Stapells, 1993; Stuart et al. 1990; Yang et al., 1987). Vander Werff found shorter bone-conduction ABR latencies at 500 Hz and longer latencies at 2000 Hz for infants compared to adults. These studies together indicate the characteristics of the infant's skull result in a more intense stimulus at the cochlea relative to adults, resulting in lower thresholds, generally shorter latencies, and larger amplitudes that are frequency dependent.

Threshold differences of greater than 15 dB, with better bone-conduction thresholds than air-conduction thresholds, is indicative of conductive involvement. Andrews and colleagues (Andrews, Chorbachi, Sirimanna, et al., 2004) evaluated 40 children with cleft palate at 3 months of age, under natural sleep, using both air- and bone-conducted click stimuli. Only 13 of the children could be successfully tested by bone conduction, while all remained asleep for air-conduction testing. The results estimated

hearing threshold levels ranging from mild to severe. Bone-conduction levels, in general, were better than air-conduction levels, indicating a probable conductive component to the hearing loss. The authors point out the responses to click stimuli are not frequency specific, and that hearing could be poorer for the lower frequencies. Therefore, there is a need to use more frequency-specific stimuli for testing. The authors concluded that the ABR was a viable means of evaluating hearing in naturally sleeping young infants with cleft palate in order to make management decisions. Unfortunately, the results also indicated that bone-conduction testing was not always feasible, as the infants did not remain in a deep enough sleep. Vander Werff et al. (2009), on the other hand, concluded that air- and bone-conduction, tone-burst ABR can be readily obtained in infants under natural sleep. They obtained air- and bone-conduction, tone-burst ABRs on a group of infants with a mean age of 10.51 weeks. They concluded that the type of hearing loss can be determined based on the air- and bone-conduction thresholds and the size of the air-bone gap.

To ensure accuracy in bone-conduction threshold testing, particular caution needs to be paid to assure adequate headband pressure (Yang et al., 1987) and proper placement of the bone vibrator on the mastoid. Most headbands are too large for young infants' heads; therefore not ensuring proper pressure of the bone vibrator on the mastoid. Adding padding to fill the gap between the headband and top of the head does nothing for the pressure but only helps to keep the headband from slipping backward or forward. Padding can be added to the side of the headband opposite the bone vibrator but may not ensure proper pressure of the vibrator against the skull. Holding the oscillator by hand pressing down on the superior surface of the oscillator is thought to perhaps mass load it and dampen the response (Wilber, 1979). Yang and Stuart (1990) developed a method using an elastic band to hold the bone vibrator and a spring scale to

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ensure appropriate coupling force. Yang et al. (1993a) used this method to measure click-evoked bone conduction ABRs in a study of at-risk infants. Currently this is a recommended method, as it helps to ensure a verifiable constant force against the skull.

Personal experience with this method has shown greater consistency between clinicians in bone-conduction responses. It resulted in more consistency in pressure among infants of various ages and sizes without adding undue time during the test session. On the other hand, Small, Hatton, and Stapells (2007) demonstrated that with proper training, a handheld coupling on the superior surface of the bone vibrator can also produce accurate results with little variability. Unverified head-band coupling can lead to considerable variability of coupling pressure. Using a handheld coupling clearly requires proper training to ensure adequate pressure.

A practical consideration in bone-conduction testing is electrode placement. Electrodes cannot be placed on the mastoid when bone-conduction testing is being done on children due to the small area of the mastoid and the potential for electromagnetic interference when the electrode is close to the bone vibrator. Placing the electrode on the earlobe or in front of the tragus is necessary for very young infants. Use of insert earphones permits placement of the bone vibrator and masking earphone on a small child's head. While bone-conduction testing often requires the use of masking, there appears to be more interaural attenuation in young children than adults (Stuart, 1990). Observance of Wave I in a response is an indication of the response coming from the ear being stimulated and may preclude the need for masking.

In summary, relatively accurate prediction of the audiogram using the ABR is possible if proper testing conditions and parameters are used. The correspondence between behavioral thresholds and ABR thresholds is good, and the two types of thresholds are within 10-20 dB of each other (Balfour et

al., 1998; Fjermedal & Laukli,1989; Gorga et al., 1985, 1988; Kileny & Magathan, 1987; Stapells, Gravel, & Martin, 1995; Stapells, Picton, & Durieux-Smith, 1994). Under good recording conditions using frequency-specific stimuli, the ABR can provide reliable estimates of sensitivity across the frequency range of hearing (Stapells & Oates, 1997; Stapells, 2000a, 2000b). For infants and young children who cannot provide sufficient information under natural sleep, it may be necessary to complete the ABR under anesthesia or sedation. Ideally, this can be coordinated with other procedures that may be necessary in the operating room or procedure center that require anesthesia or sedation.

The goal of evoked potential testing is to predict the audiogram sufficiently, so that if a sensory impairment is present, amplification can be fitted. The optimal time to conduct an ABR on a child is during natural sleep. There is always an uncertainty as to how long a child will sleep, even when sedation is used, unless conducted under very controlled environments, such as a procedure room or operating room, where anesthesiologists are controlling the state of the child. There should be a prioritization of the sequence of frequencies used during testing, as sleep state may not sustain or it may become very costly in the case of anesthesiology-controlled state. If the ABR is initiated to click stimuli or 2000 Hz tone burst, the next step would be to follow this stimulus with a low-frequency stimulus, such as a 250 or 500 Hz tone burst. Next, more frequency-specific (4000 and 1000 Hz tone burst) and bone-conduction testing should be completed. While this is a general guideline on the sequence of testing, each child's findings must be viewed and decisions made individually to maximize information obtained about the type, degree, and contour of impairment. For example, if the findings to click stimuli suggest that an impairment is conductive (i.e., prolonged latencies of all waves), then testing by bone conduction might follow the click with low-frequency testing last. If the click results imply

a sloping configuration (based on the latency intensity functions and thresholds obtained), then testing should be done using a high-frequency stimulus followed by a low-frequency stimulus, with testing by bone conduction last.

The ABR measures the integrity of a portion of the auditory system through approximately the level of the midbrain. It does not measure "hearing" in the true meaning of the word. As stated earlier, while agreement exists between behavioral thresholds and ABR thresholds, there are instances where they will not agree. There are cases of normal ABR, yet no ability to recognize or use sound to "hear." Conversely, and more common than normal ABR and no response to sounds, is the absence of an identifiable waveform on an ABR test that does not necessarily equate to thresholds in the severe-to-profound range—or "no hearing." ABR equipment is more limited in output than most audiometers used to test behavioral thresholds. Consequently, an absent ABR should not be interpreted as having no residual hearing. The ABR is affected by the neurologic status of the child. If the auditory system is damaged and neurons cannot fire synchronously, or if there are disruptions of the auditory pathway due to an insult, there will be no identifiable ABR waveform or a partial waveform with later waves absent, even though the end organ of hearing (the cochlea) may be functioning normally. With the availability of technology to monitor otoacoustic emissions (OAEs) from the cochlea, discrepancies between behavioral audiologic findings and ABR may be more effectively resolved. For example, in situations where behavioral audiologic findings show better responses to sound than can be predicted by the ABR, the behavioral findings are being substantiated by the presence of OAEs.

Auditory Steady-State Response (ASSR) Testing

The ASSR is an evoked potential test that holds promise for predicting frequency-specific thresholds in individuals who cannot provide reliable or valid behavioral thresholds, such as infants and young children (Cone-Wesson, Dowell, Tomlin, Rance, & Ming, 2002; Dimitrijevic, John, Van Roon, et al., 2002; Rance, Roper, Symonds, et al., 2005; Vander Werff, Brown, Gienapp, Schmidt, & Kelly, 2002). It is often used as a supplement to ABR testing. An advantage of this measure is that response presence or absence is based on statistical analysis, not on visual inspection methods, and can provide slightly greater intensity levels of the stimuli.

Like the ABR, the 80 Hz ASSR is believed to be generated primarily by the brainstem (Herdman et al., 2002). Relatively tonal stimuli (carriers) that are amplitude and/or frequency-modulated are used to evoke the ASSR, and in turn, the ASSR can provide frequency-specific estimates of air-conduction hearing levels. The modulation frequency is appropriate for infants and children (80–100 Hz) and can be used for infants and young children who are sleeping (Cohen, Rickards, & Clark, 1991). Single or simultaneously presented stimuli have been used to elicit the ASSR (Picton, John, Dimitrijevic, & Purcell, 2003). The test also allows for simultaneous monitoring of both ears, making it attractive for testing pediatric patients, because testing time should be less than that needed for ABR testing. However, the ASSR needs more research, particularly in its application to infants and young children with respect to length of time needed to obtain full information about a child's hearing levels.

Threshold prediction using the ASSR conducted on adults and children with hearing loss has been shown to provide fairly accurate estimates of the behavioral audiogram (Alaerts, Luts Dun, Desloovere, & Wouters, 2010; Aoyagi, Suzuki, Yokota, Furuse, Wantanabe, & Ito, 1999; Lins, Picton, Boucher, & Durieux-Smith,1996; Rance, Dowell, Rickards, Beer, & Clark, 1998; Rance, Rickards, Cohen, et al.,1995; Stueve & O'Rourke, 2003; Swanepoel, Hugo, &

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Roode, 2004; Vander Werff et al., 2002). Hearing thresholds have been estimated within about 10 to 15 dB in adults with normal hearing and hearing loss using the multi-frequency ASSR (Dimitrijevic et al., 2002; Kaf, Durrant, Sabo, Boston, Taubman, & Kovacyk, 2006). Less research is available on infants and children. Perez-Abalo et al. (2001) found that hearing loss in the severe and profound range could be accurately determined, but only fair agreement was observed between ASSR thresholds and hearing levels in children with mild hearing loss or normal hearing. Tlumak, Rubinstein, and Durrant (2007) concluded, based on a meta-analysis, that 80-Hz ASSR is a reasonably reliable method for estimating hearing sensitivity in the mid- to high frequencies in those with and without hearing loss. More accurate threshold estimations, using 80-Hz ASSR, are obtained as carrier frequency increases for those with hearing loss. In addition, there are differences between 80-Hz ASSR mean thresholds found between monaural and binaural multiple frequency stimulus conditions, at least for those with hearing loss.

The influence of age on the ASSR suggests that maturation has some influence on threshold determination in very young infants. Rance and Rickards (2002) found that the prediction of hearing thresholds was similar between young (1 to 8 months) infants and older subjects with hearing loss. However, results obtained from infants with normal hearing have suggested that maturational factors that are sufficient to affect the differentiation between normal hearing and mild-to-moderate hearing loss may influence the findings of ASSR assessments carried out in the first few weeks of life (Cone-Wesson et al., 2002; Levi, Folsom, & Dobi,1995; Lins et al., 1996; Rance & Rickards, 2002; Rance et al., 2005; Rickards, Tan, Cohen, Wilson, Drew, & Clark, 1994; Savio, Cardenas, Perez, Gonzalez, & Valdes, 2001). Rance and Tomlin (2006) evaluated neonates and young infants with normal hearing and found that ASSR threshold levels were different from those observed in older subjects. They concluded that when the ASSR is used clinically, it is necessary to take into account developmental changes occurring in the first weeks of life. Furthermore, their findings indicated that ASSR thresholds in normal-hearing babies at 6 weeks of age were not yet mature.

Limited data exist regarding the use of ASSR employing bone-conduction stimulation. Small and Stapells (2006) used multiple bone-conducted stimuli that were both frequency and amplitude modulated in a group of preterm infants (32-43 weeks) and a group of full-term infants (0-8 months). The results obtained for infants were different from those obtained for adults. For infants, the threshold estimates were better in the lower frequencies and poorer in the higher frequencies when compared to adults. Swanepoel, Ebrahim, Friedland, Swanepoel, and Pottas (2008) evaluated bone-conduction stimulation in a group of older children and concluded that the stimulus artifact prevents determination of type of hearing loss in most cases of sensorineural hearing loss but interferes less when

Photo courtesy of NCHAM

conductive hearing losses are present. However, the results varied with frequency in both situations. This tool has much promise for assessment of infants and young children, but further research and refinement in all aspects of the ASSR are needed to determine if it will produce accurate audiogram predictions in all infants and young children.

Otoacoustic Emissions

Otoacoustic emissions are sounds that originate from physiologic activity inside the cochlea and can be recorded in the ear canal. The literature is rich with evidence that this activity is associated with normal to near normal hearing processes. The exact generator of the OAEs is not well understood, although the sensory (outer) hair cells within the organ of corti (which sits on the basilar membrane) are thought to be responsible for the generation of OAEs. OAEs give us the ability to view the functioning of the cochlea, although not without contribution of the middle ear. Sounds created in the cochlea are passed through the middle ear via the ossicular chain and eardrum (i.e. , the middle ear bones that are linked together and coupled to the eardrum) and are recorded by placing a microphone in the ear canal.

Healthy middle ears that can transmit sound to and from the cochlea effectively are essential to being able to record OAEs. Recording OAEs allows measurement of cochlear function objectively and noninvasively. OAEs are generated exclusively by outer hair cells. Most hearing losses do not involve inner hair cell damage. Outer hair cells are generally more vulnerable to disease and damage than inner hair cells. The presence of an OAE provides us with reasonable assurance that hearing thresholds are 30 to 40 dB or better in the frequency range where the emission is present. OAEs may be absent due to middle ear dysfunction (i.e. , the inability of the emission to be transmitted effectively through the middle ear or due to a sensory hearing loss affecting the outer hair cells). OAEs, however, cannot accurately predict

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hearing levels, and their presence does not ensure normal hearing. In young children, OAEs are often of low amplitude relative to physiologic and ambient low-frequency noise (1000 Hz and below). Consequently, absent OAEs in low-frequency regions alone are insufficient for determining presence or absence of hearing loss.

The OAE should constitute one test in a battery of tests for accurate interpretation. OAEs are sensitive to hearing losses and can be absent with as little as a 20 to 30 dB HL hearing loss. The absence of an OAE response, however, must be viewed within the context of the condition of the middle ear, since both the stimulus and response pass through the middle ear. Absence of an OAE is diagnostically significant for sensorineural hearing loss only when middle ear function is relatively normal. Consequently, middle ear status needs to be evaluated and rounds out the clinical profile of hearing in children by combining OAEs, ABR, behavioral audiometry, and acoustic immittance test results.

Acoustic Immittance Measures

Tympanometry

Acoustic immittance testing helps to differentiate and/or substantiate other test findings. Acoustic immittance testing consists of tympanometry and acoustic reflex testing and can be completed on children of all ages. Quantitative values of acoustic admittance (Y_{tm}), tympanometric peak pressure (TPP), equivalent ear-canal volume (V_{eq}), and tympanometric width (TW) may be readily obtained in most children. Identification of abnormal middle ear function is defined by evaluating these characteristics relative to normative values (American Speech-Language-Hearing Association, 1988, 1997; American Academy of Audiology, 1997). Several studies have evaluated tympanometric test findings in children with otitis media (Nozza, Bluestone, Kardatze, & Bachman, 1992, 1994; Rouch, Bryant, Mundy, Zeisel, & Robers, 1995; Silman, Silverman, & Arick, 1992). Nozza

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et al. (1994) in particular, found that tympanometric width of >275 daPa had the best test performance for any single 226 Hz tympanometric characteristic—with sensitivity and specificity of 81% and 82%, respectively. Similar findings were obtained in a large group of infants and children showing that the greater the width and lower the height, the greater the association with middle ear effusion (Smith, Paradise, Sabo et al., 2006). Standard tympanometry uses a low-frequency probe tone of 220 or 226 Hz for measurement. However, the interpretation of the tympanogram and acoustic reflex findings may be compromised when this probe tone is used with infants less than 4 months of age.

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Calandruccio, Fitzgerald, & Prieve, 2006). Several studies (Kei et al., 2003; Margolis et al., 2003) have provided normative 1000 Hz tympanometric data, although more recently a simplistic visual criteria of peak vs. no peak has been found to be effective (Mazlan, Kei, Hickson, Gavranich, & Linning, 2009; Zhiqi, Kun, & Zhiwi, 2010).

Acoustic Reflex

The acoustic reflex can be a very useful part of the audiologic evaluation in infants. A present reflex is added support for determining normal middle ear function. It is also important to use a high-frequency probe to measure the acoustic reflex in infants under 6 months of age (Weatherby & Bennett, 1980; Kei, 2012).

Widband Acoustic Immittance

Wideband acoustic immittance is an emerging method of assessing middle ear function, but it is not yet in general use. Wideband acoustic immittance is a general term that encompasses reflectance and absorbance measures. The research on wideband acoustic immittance suggests that it could improve diagnosis of middle ear conditions in infants and children when compared to single-frequency tympanometry (Keefe, Zhao, Neely, Gorga, & Vohr,2003; Keefe, Gorga, Neely, Zhao, & Vohr, 2003; Hunter, Tubaugh, Jackson, & Propes, 2008). Wideband acoustic immittance measures do not require pressurization of the ear canal and use a wide-frequency range of 62 to 10,000 Hz to provide more information on middle ear status than tympanometry (Keefe, Bulen, Arehart, & Burns, 1993; Keefe & Levi, 1996; Piskorski et al., 1999; Feeney, Grant, & Marryott, 2003; Keefe & Simmons, 2003; Hunter, Bagger-Sjoback, & Lundberg, 2008; Shahnaz et al., 2009; Beers et al., 2010; Ellison et al., 2012; Keefe et al., 2012; Prieve et al., 2013).

Wideband acoustic reflectance, scaled between 0.0 and 1.0, is the ratio of the energy reflected from the tympanic membrane to the incident energy presented in the ear canal. Zero is obtained when

The American Academy of Audiology recommends not using "audiometry" to describe this method, as it cannot determine hearing thresholds. The AAA strongly feels that the term "audiometry" should only be used for those tests that can determine threshold levels.

all energy is absorbed by the middle ear, and one is obtained when all energy is reflected from the tympanic membrane. In a normal-functioning adult ear, the wideband acoustic reflectance values change with frequency, such that values closer to 1 are obtained in the low frequencies, with decreasing values to about 4000 Hz and increasing values at higher frequencies. Aithal, Kei, Driscoll, and Khan (2013) recently published normative wideband reflectance measures in healthy neonates who passed high-frequency tympanometry, acoustic reflex testing, transient ocoacoustic emissions (TEOAE), and distortion product otoacoustic emissions (DPOAEs). Their findings are similar to those of Hunter, Feeney, Miller, Jeng, and Bohning (2010) and Merchant, Horton, and Voss (2010) but differed from those of Sanford et al. (2009), although there were methodological differences between the studies.

In 2008, Hunter et al. evaluated wideband reflectance, standard 226 Hz and 1000 Hz tympanometry, in infants and children with cleft palate. The results were compared to DPOAEs, which are sensitive to conductive hearing losses and middle ear dysfunction. While 1000 Hz tympanometry had better agreement with DPOAEs (80% agreement) than standard 226 Hz tympanometry (73% agreement), wideband reflectance had the best agreement with 88%. The agreement in the general population of newborns of 1000 Hz tympanometry and OAEs ranges from about 50% (Margolis et al.,2003; Swanepoel, Werner, Hugo, et al., 2007) to 99% sensitivity and 89% specificity in a study by Baldwin (2006) . While the results are promising for the use of wideband reflectance, more research is needed to fully understand the strengths and limitations of this method.

Behavioral Audiometric Testing

Behavioral Observation

Behavioral Observation Audiometry (BOA) is a method of observing infants' responses to auditory stimuli, but falls short of being able to predict threshold levels. The American Academy of Audiology (2012) recommends not using "audiometry" to describe this method, as it cannot determine hearing thresholds. The AAA strongly feels that the term "audiometry" should only be used for those tests that can determine threshold levels. Behavioral observation provides information about the type of auditory response the child makes and the auditory development of the child. However, the presence of overt responses to auditory stimuli cannot be used to predict speech and language development. Knowing the type of auditory response that a child makes provides a basis for knowing what responses parents and audiologists should look for once amplification is introduced.

Visual Reinforcement Audiometery

For children over 5 to 6 months of age, the preferred technique is Visual Reinforcement Audiometry (VRA). VRA is an operant conditioning technique that allows for a head turn response that often occurs spontaneously to sound to be maintained through the use of visual reinforcement. VRA may be used in sound field, but obtaining ear- and frequency-specific information is only accomplished using insert earphones. Not all children will complete testing for both ears in one visit. To maximize the quantity of information obtained during a clinic visit, the order of stimuli presentation should be prioritized to provide the maximum amount of information about the degree and configuration of the hearing loss. A good starting point for conditioning is to use speech stimuli, because children often find this more interesting than tonal stimuli and respond naturally with a head turn response, which then can be reinforced.

Much like the ABR, the order of testing various frequencies—alternating a high and low frequency—will yield an audiogram that provides some, if not all, information necessary to predict the contour of a hearing loss. For example, 2000 Hz might be the starting frequency,

followed by 500 Hz, 4000 Hz, and then 1000 Hz. If the child stops responding before all of the frequencies have been tested, partial results can give at least an idea of the contour of the hearing loss and impact on the audibility of speech.

In the case of a suspected severe-to-profound hearing loss, if there is a lack of responsiveness at higher frequencies, the clinician should move quickly to a stimuli at 500 Hz or below. When conditioning to tonal stimuli cannot be achieved, the use of a bone vibrator with a low-frequency stimulus at high-intensity levels should be attempted. The goal is to achieve conditioning to a tactile response in order to verify that the child is capable of doing the task. Possibly, the stimulus was not audible (when presented via phone), and therefore the reason conditioning to auditory stimulus was not achieved. By using reversals (i.e., change from decreasing-to-increasing or increasing-to-decreasing stimulus levels), the number of responses obtained before the child fatigues can be increased. It is reasonable to include four to five (two to three responses) reversals in a testing session. The anticipated starting point can be inferred from the SAT or SRT, and bracketing can then be done. Some

children require reconditioning when going from frequency to frequency. Therefore, it may be necessary to present stimuli above anticipated threshold to remind the infant what to do.

Control trials—or trials with no stimulus to observe random head turning behavior—should be used to rate the reliability of the session by determining the number and percentage of false positive responses that occur. A false positive rate greater than 30% would indicate that the data from that session was not reliable enough to make a statement about the child's hearing. Use of control trials is the best way to reduce subjectivity and ensure valid findings.

If the child can be conditioned, the child's maturational or developmental level does not influence the threshold level. Thresholds obtained using VRA do not differ substantially from those obtained with adults (Nozza, 1995; Olsho, Koch, Carter, Halpin, & Carter, 1987). In general, a decrease in threshold level is not observed with an increase in age, as long as adequate conditioning is achieved (Wilson & Moore, 1978). Vander Werff et al. (2009) obtained threshold levels of less than 20 dB using insert earphones in infants less than 12 months of age. These results reinforce VRA findings using insert earphones (Widen et al., 2000, 2005; Parry et al., 2003) and are similar to Sabo et al. (2003), who measured hearing levels in the sound field. In addition to VRA providing assessment of thresholds, it also provides information regarding the integrity of the auditory pathway and the child's ability to detect or discriminate auditory stimuli.

Play Audiometry

Play audiometry—sometimes referred to as conditioned play audiometry—is the term used to describe a technique in which a game activity is

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The relationship between the audiologist and family changes over time as the family acquires the necessary knowledge and skill to become their child's advocate.

used to obtain threshold information. Play audiometry can be used starting at approximately 24 months of age, but is better at 2 1/2 to 3 years of age. Play audiometry involves conditioning the child to respond to sound using an activity, such as placing a peg in a pegboard, placing blocks in a container, stacking rings on a stick, or placing puzzle pieces into a puzzle. Little verbal instruction should be given to the child, but modeling of the expected behavior must be done. If successful, conditioning usually occurs after four or five guided responses or demonstrations. Often a social reinforcement, such as clapping hands or praising the child, is used to help to establish conditioning. With this technique, frequency-specific and ear-specific information can be obtained to both air- and bone-conduction stimulation. For very young children or children who have difficulty staying on task, the sequence of frequencies should emphasize obtaining information necessary to predict the contour and degree of hearing loss. Complete testing of one ear need not be done before the opposite ear is tested. Often if a child is responding consistently to a specific frequency in one ear, that same frequency can be rapidly tested in the opposite ear before moving to another frequency. It may be preferable to get partial frequency information from both ears rather than complete information from one ear.

Conventional Audiometry

Conventional audiometry can be used by the time the child is 5 to 6 years of age. The response is typically the same as that used for adults, such as conditioning the child to raise their hand in response to the sound. As with all behavioral test techniques, the developmental level of the child and not the chronological age determines which technique will be most appropriate.

To summarize, behavioral audiologic techniques can yield reliable results, but care must be taken to eliminate false positive responses. Using control trials to observe the child's responses during times of no stimulus can reduce false positive results. Awareness of parental cueing (often unintentionally), patterning of presentation cues, or examiner bias can help to reduce subjectivity and error.

Audiologic information is necessary in order to begin the habilitative process. The necessary audiologic evaluation for the pediatric population, however, does not end with the audiogram. Counseling, family support, and management of the hearing loss are integral components of the evaluation.

When a child comes to the clinic, they always bring a family. Audiologists are faced with the challenges of obtaining accurate audiologic information *and* helping the families with their acceptance and readiness to advance into habilitation if a hearing loss is identified. The audiologist's skill in obtaining accurate audiologic information is important, but so is their ability to counsel and effectively communicate with the child's family. Management of hearing loss in children starts with family counseling prior to moving onto fitting of amplification and enrollment into an educational program geared to helping those with hearing loss, such as early intervention. While the hearing aid fitting process is beginning, referral to and enrollment in an early intervention program is a must, so that the families have the educational help and support they need on an ongoing basis.

Counseling begins the moment you introduce yourself to the family. It is at that time that you start to build the trusting relationship that will be the cornerstone for effective counseling and follow-up. Counseling should not be thought of as something that occurs in a particular time sequence or has a definite beginning and end point. Counseling, like most other aspects of pediatric audiology, is an ongoing process. Counseling should involve not only providing information but creating a supportive environment for families to work through the myriad of emotions they will experience.

Information provided to families needs to be redundant, given in various forms, and repeated often. They need to receive information that is balanced and addresses the options available in their local area.

The relationship between the audiologist and family changes over time as the family acquires the necessary knowledge and skill to become their child's advocate. This shift will change the counseling sessions from the audiologist being the "expert" providing information on hearing and hearing loss to the family assuming the "expert" role as they become aware of what information they need and experts on their child's needs. There is no set time for this change to occur, since each child and family is different with different needs, emotions, and abilities. Each family will set its own pace of acceptance and becoming an advocate for their child. Our role as pediatric audiologists is to help families reach this point.

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