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Studies in Pediatric Hearing Loss at the House Research Institute

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Abstract

Three clinical research projects are described that are relevant to pediatric hearing loss. The three projects fall into two distinct areas. The first area emphasizes clinical studies that track developmental outcomes in children with hearing loss; one project is specific to cochlear implants and the other to hearing aids. The second area addresses speech perception test development for very young children with hearing loss. Although these two lines of research are treated as separate areas, they begin to merge as new behavioral tests become useful in developing protocols for contemporary studies that address longitudinal follow-up of children with hearing loss.

Keywords

Adaptive behavior; cochlear implants; development; hearing aids; pediatric hearing loss; speech perception

Howard P. House, M.D., founded the House Research Institute in 1946 under its original name, the Los Angeles Foundation of Otology. A decade later Howard's half brother, William F. House, M.D., joined him in medical practice and research endeavors. Whereas Howard House had perfected middle ear surgery, William House moved beyond this realm by delving into the inner ear and related structures. And, as a result of these efforts, William House has become known as the Father of Neurotology because of his groundbreaking innovations in inner ear and skull base surgery. Three of his most significant contributions relate to acoustic tumor surgery, cochlear implants, and auditory brainstem implants.

As one of the clinical pioneers in cochlear implantation, William House began to investigate the feasibility of this technology in the 1960s. Multicenter trials that were designed to evaluate cochlear implants in large numbers of patients eventually became a reality because of Dr. House's persistence. By 1980, after much experience implanting pre- and postlingually deafened adults, William House made the decision to implant a congenitally deaf 10-yr-old. Hence, the era of pediatric cochlear implantation was launched (for a history see Eisenberg, 2009). As a direct result of this event, the Center for Deaf Children was founded at the House Research Institute. The Center primarily treated children with profound hearing loss during the early single- and multi-electrode implant trials. By 1990, the Center had expanded into a fully functioning diagnostic facility for pediatric hearing loss and was renamed the Children's Auditory Research and Evaluation (CARE) Center. As part of this expansion, a research component was added and integrated into the clinical activities of the CARE Center.

The current status on three CARE Center research projects are described in this article. All three projects have been funded by the National Institute on Deafness and Other Communication Disorders (NIDCD) of the National Institutes of Health (NIH). Two of these projects involve multicenter collaborations, one specific to cochlear implants (Childhood Development after Cochlear Implantation) and the other to hearing aids (Development and Adaptive Behavior of Young Children with Hearing Loss). Both projects focus on developmental outcomes. The third project is specific to the development of speech perception tests for infants, toddlers, and preschool-age children (Assessing Auditory Capacity in Hearing-Impaired Children).

CHILDHOOD DEVELOPMENT AFTER COCHLEAR IMPLANTATION (CDaCI)

CDaCI is a multicenter study initiated in 2002 to examine contributing factors associated with spoken language development in young children with cochlear implants (Niparko et al, 2010). The clinical sites participating in this longitudinal study are Johns Hopkins University, University of North Carolina, University of Miami, University of Texas at Dallas Callier Center, and the House Research Institute. Enrolled are 188 children with severe to profound hearing loss and 97 normal-hearing peers enrolled younger than age 5 yr (Fink et al, 2007). The participants are being followed longitudinally on an extensive battery of tests encompassing the domains of language, speech recognition, psychosocial functioning, and quality of life.

In addition to being one of the six enrollment sites, we have led the effort in developing a speech recognition assessment protocol for this study. A battery of tests has been compiled that in most cases incorporates measures typically administered in pediatric cochlear implant centers. Although individual tests in the battery are administered according to the age requirements of the test, the battery itself is hierarchical. That is, the child is required to attain criterion performance on an easier test before advancing to the next, more difficult, test in the hierarchy, irrespective of age at time of testing. The advantage of the hierarchical approach is that assessment is more efficient because floor and ceiling effects are substantially reduced. The test battery progresses from structured parent report to closed- and open-set measures of speech recognition. Most of the tests are administered in quiet, but some incorporate background speech or noise conditions (Eisenberg et al, 2006). Table 1 displays the tests that comprise the CDaCI speech recognition hierarchy. It is notable that this hierarchy has been adapted for a large-scale pediatric cochlear implant study in China (Zheng et al, 2009a, 2009b, 2009c).

At the time of this writing, 78 children are bilateral cochlear implant users. A binaural protocol has been incorporated into the battery using the adaptive Hearing in Noise Test for Children (HINT-C) (Nilsson et al, 1996). Another modification includes presenting the tests in the auditory-visual modality for those children who have not progressed beyond pattern perception on the Early Speech Perception (ESP) test (Moog and Geers, 1990).

Because not all children are assessed on the same tests at each follow-up interval, Wang et al (2008) designed an index that displays individual data points according to the child's age at a specific test interval. Referred to as the Speech Recognition Index in Quiet (SRI-Q), each of the tests administered in quiet is assigned a range of values within a 100-point range and then stacked from easiest to most difficult to create a range of 0–600 (as can be seen in Fig. 1). The score of 300 marks the boundary between performance on parent report and closed-set tests (0–299) and open-set tests (300–600). Individual data points on the SRI-Q represent the highest level achieved at a specific age and test interval. An advantage of the SRI-Q is that it facilitates rate of growth analysis as children advance through the hierarchy. Figure 1 displays performance outcomes from baseline (pre-implant for the children with implants)

and the 3 yr test interval as a function of the child's age at time of testing (Johnson et al, 2010; Eisenberg et al, 2010). The gray circles and solid black line represent the data for the children with cochlear implants; the open squares and dashed black line are the symbols for data of the children with normal hearing. In the left panel it will be seen that floor effects predominated before implantation (baseline), although it is notable that a few children achieved closed- and limited open-set word recognition with their hearing aids. The children with normal hearing achieved near ceiling on age-appropriate tests at baseline when compared to the children with hearing loss before implantation. The right panel displays the 3 yr follow-up data. Approximately 70% of the children with implants had advanced to open-set tests but still lagged behind their normal-hearing peers. As is typical with the pediatric implant population, there is high variability, and about 10% of the children had not progressed beyond pattern perception on the ESP by the time that they reached the 3 yr test interval.

One limitation of the SRI-Q is that only those tests administered in quiet are represented. The tests that are administered in background competition still need to be incorporated into the index. However, until a more comprehensive representation of the data becomes available, the SRI-Q provides a convenient way to display longitudinal data for a large group of pediatric cochlear implant users as well as highlight single data points for individual children.

As an example of the utility of the SRI-Q, speech recognition data points are plotted from two pediatric auditory brainstem implant (ABI) patients currently being managed in the CARE Center. Viewed in Figure 2 (left panel), the 2 yr follow-up results for these two children are displayed alongside the CDaCI study participants (cochlear implant and normal hearing) at the same test interval. Subject ABI-02, who was implanted at 1 yr, 11 mo, met criterion on the most difficult level of the ESP (consistent word identification presented live voice) after 2 yr of experience. Subject ABI-03, who received the device at 2 yr, 11 mo met criterion for pattern perception on live-voice presentation of the ESP. In the right panel, the 3 yr follow-up results are plotted for ABI-02 only against the same data shown in Figure 1 (right panel). This child jumped one level in one year on the SRI-Q, achieving a score of 100% on recorded Pediatric Speech Intelligibility (PSI) sentences (Jerger et al, 1980). Although both of these children perform at lower levels when compared to the average data for children with cochlear implants of a similar age, they still are shown to be performing within the overall range of performance. It remains for further follow-up to determine whether open-set speech recognition will be attained. In another application, Buchman et al (2011) utilized the SRI-Q in evaluating cochlear implant performance among children with cochlear malformations and cochlear nerve deficiency.

DEVELOPMENT AND ADAPTIVE BEHAVIOR OF YOUNG CHILDREN WITH HEARING LOSS (DABCHL)

With the successful practice of early hearing detection and intervention programs, a more contemporary understanding about pediatric hearing loss is warranted. This is particularly true for newly identified infants with mild to severe hearing loss fitted with acoustic amplification—a group that receives less attention in the research literature. Although studies can be found in the research literature that describe auditory and communication outcomes in this population (Yoshinaga-Itano et al, 1998; Moeller, 2000; Kennedy et al, 2006; Sininger et al, 2010), relatively little is known about the variables that facilitate optimal social-emotional and adaptive functioning for these young children in real-world environments. The DABCHL study was initiated in 2008 to identify factors that contribute to developmental outcomes in children with mild to severe hearing loss who are fitted with hearing aids. This investigation takes a transactional/ecological approach of child

development. Such an approach asserts that development in young children is influenced by many interrelated factors, including biologic, social, and cultural. The DABCHL study combines longitudinal and cross-sectional designs to determine the developmental trajectories from infancy to pre-school age.

Three centers collaborate on DABCHL—House Research Institute, San Diego State University, and Indiana University School of Medicine. Children with mild to severe hearing loss and with normal hearing are enrolled between the ages of 12 and 48 mo. The children are assessed within the developmental domains of audition/speech perception, language, cognition, social-emotional problems/competencies, and adaptive functioning. Parents are assessed in terms of their involvement and self-efficacy, emotional availability, and language input. Specific information about intervention services will be delineated throughout the investigation.

At the time of this writing, 27 children with mild to severe hearing loss and 63 children with normal hearing are actively enrolled into the DABCHL study. Stika et al (2011) recently presented outcomes on the first 20 children with hearing loss (mean age 17.8 mo) and 57 children with normal hearing (mean age = 21.6 mo). The outcomes were specific to measures of cognition, language, adaptive behavior, and social-emotional development. As can be seen in Table 2, mean performance outcomes for both groups of children fall within the average range on all measures and subscales examined. Despite this impressive finding, it will be seen that the mean scores for the children with hearing loss are consistently lower than those for the children with normal hearing across all measures. Statistically significant differences are shown between groups for three out of the five subdomains for the Mullen Scales of Early Learning (Mullen, 1995) and for expressive language on the Preschool Language Scale (Zimmerman et al, 2002). Differences are not statistically significant for the Vineland Behavior Scales (Sparrow et al, 2005) and the Infant-Toddler Social and Emotional Assessment (Carter and Briggs-Gowan, 2005, 2006).

It is not clear whether the developmental trajectories for these two groups will continue to be similar or will diverge as additional children with hearing loss are recruited into the study and as children from both groups advance in age. Irrespective of these outcomes, the knowledge gained from this study is expected to inform developmental theory and promote effective child and parent support interventions for young children with mild to severe hearing loss.

ASSESSING AUDITORY CAPACITY IN HEARING-IMPAIRED CHILDREN

Assessing Auditory Capacity in Hearing-Impaired Children is a project that was initiated in 2003 to investigate auditory-perceptual development in young children identified with hearing loss. The means by which to accomplish this goal has necessitated the development and refinement of behavioral assessment tools to measure speech perception in children between the ages of 6 mo and 5 yr. With the establishment of a progressive test battery, changes over time in speech perception performance may be measured as a function of the child's age, assessment task, auditory status, and sensory assistance. Moreover, the different tests will enable examination of the relationships between speech perception and other auditory-based outcomes, such as speech production and language skills, at very young ages. The battery is composed of tests that measure speech pattern contrast perception, phoneme identification, and word recognition (in isolation and sentence context). A description of the tests and progress accomplished to date are summarized below.

Speech Pattern Contrast Perception

Measures of speech pattern contrast perception for older children and adults with hearing loss were developed several decades ago by Arthur Boothroyd (1984, 1985, 1991). We joined forces with Dr. Boothroyd to create similar measures of speech pattern contrast perception appropriate for infants, toddlers, and pre-school-age children. Four such measures have been designed and/or refined for children between the ages of 6 mo and 5 yr (Eisenberg et al, 2007; Boothroyd, 2009). Although the response task differs for each test to be consistent with the child's age and abilities, the perceptual task remains constant across the four tests. Designed to minimize higher level linguistic processing, these tests assess the child's ability to perceive phonetic contrasts when listening to vowel-consonant-vowel (VCV) stimuli spoken by a female talker. The contrasts being assessed are vowel height and place, and consonant voicing, continuance (manner), and place in the bilabial-alveolar (front) and alveolar-palatal (rear) position. The tests are under computer control to facilitate standardization and automatic computation of performance and data logging. The four tests are described below.

Visual Reinforcement Assessment of the Perception of Speech Pattern

Contrasts (VRASPAC)—Stemming from earlier research by Eilers et al (1977), VRASPAC was designed to measure speech pattern contrast perception in infants. The task relies on a conditioned head-turn in response to a phonetic change within a repetitive string of VCV stimuli (e.g., oodoo, oodoo, oodoo, aadaa, aadaa, aadaa). The VRASPAC algorithm utilizes a preset stopping rule that is determined by a confidence-level criterion that the infant's head turn occurs within a hypothetical time window following initiation of the contrast. The algorithm automatically stops after a specified number of presentations should criterion not be met. Martinez et al (2008) analyzed VRASPAC results in two groups of infants, one with normal hearing and the other with hearing loss. Both groups achieved high confidence levels for vowel height. For vowel place, the group with normal hearing achieved high confidence levels. The confidence levels for the group with hearing loss varied across infants, particularly for those with greater severity of hearing loss. Consonant contrast perception was variable for both groups of children. At this time, assessment of vowel contrasts is recommended for babies younger than 2 yr of age. Notably, the VRASPAC algorithm was used in a study by Uhler et al (2011) for tracking speech perception development in babies fitted with cochlear implants. Incorporating vowels in isolation and CV syllables, these investigators demonstrated that babies were able to master most or all of the contrasts after 2–3 mo of experience with the cochlear implant. The Uhler results suggest that VCV stimuli used in our studies may be too complex for infants.

Play Assessment of Speech Pattern Contrasts (PLAYSPAC)—Adapted from a test developed by Dawson et al (1998), PLAYSPAC utilizes a conditioned-play testing paradigm in which the child engages in a motor activity (e.g., putting a peg in a board or pushing a button) upon perceiving the contrast. Similar to VRASPAC, an automatic stopping rule indicates when the criterion level is either attained or not attained. PLAYSPAC data have been collected as part of Sophie Ambrose's dissertation on phonological awareness of young children with cochlear implants (Ambrose, 2009; Ambrose et al, forthcoming). Data were analyzed for children with normal hearing ($n = 23$) and children with cochlear implants ($n = 19$), ranging in age from 36 to 59 mo. The majority of children (both normal hearing and hearing impaired) achieved the 90% confidence level for vowel height and place. All but two of the children with normal hearing achieved high confidence levels for the consonant contrasts. The two children who didn't meet the 90% criterion were in the younger age range. A number of children with cochlear implants achieved high levels of performance on the consonant contrasts; however, some did not, particularly for continuance and voicing. In contrast to the VRASPAC findings, these data

suggest that by the time children with cochlear implants reach the age of 3 yr and older, they are generally able to be assessed on all contrasts used in this task.

On-line Version of an Imitative Test of Speech Pattern Contrast Perception (OLIMSPAC)—This test measures the child's ability to produce, by imitation, utterances that convey phonologically significant information for the contrasts being evaluated. In its original implementation (IMSPAC), the child's responses were recorded and edited for off-line evaluation by teams of normal-hearing listeners (Boothroyd, 1985; Kosky and Boothroyd, 2003). A more clinically applicable version of the test was needed, so an on-line version was developed as part of this project and an earlier subcontract with UCLA that enables real-time scoring (Eisenberg et al, 2003; Sininger et al, 2010). Because OLIMSPAC requires the child to repeat each stimulus item, phonological knowledge and motor speech skills are a prerequisite for testing. The OLIMSPAC is typically administered in the auditory-visual (AV) and the auditory-only (AO) modalities. After the child repeats the VCV token, the tester selects the stimulus item that best approximates the child's utterance from a choice of eight alternatives. The tester is masked from hearing and seeing the target stimulus to ensure objectivity. The test is scored by percent correct rather than percent confidence (although percent confidence is an option for comparison with the other tests). Results on an early prototype of OLIMSPAC (using CV stimuli) compared performance between normal-hearing and hearing-impaired children. The following results were found: scores were lower than those obtained by children with normal hearing; AV scores were higher than AO scores; and vowel contrasts are perceived more accurately than consonant contrasts (Eisenberg et al, 2003).

In a recent study by Boothroyd et al (2010), the OLIMSPAC was administered to 30 children with normal hearing, 2.5 to 6.5 yr of age to establish the youngest age at which the test may be appropriate for administration. Performance on OLIMSPAC was not affected by presentation modality but was influenced by contrast and child's age. There also were large individual differences, especially for the younger children. The age at which the average child attained 90% accuracy on most contrasts was 3 yr. The exception was place of consonant articulation (post alveolar). The AO component of OLIMSPAC has been reported in other studies. Sininger et al (2010) showed that age of fitting of hearing aids was predicted by OLIMSPAC. In a study by DesJardin et al (2009), performance on OLIMSPAC was related to receptive and expressive language scores and other measures derived from spontaneous language samples in preschool-age children with hearing loss.

Video-Game Speech-Pattern Contrast Test (VIDSPAC)

VIDSPAC is similar to VRASPAC and PLAYSPAC but uses a video game format (Boothroyd, 1991). The test also provides reinforcement and offers rewards in the form of cartoons. The child responds to the contrast by pushing a button that interfaces with the computer. VIDSPAC also is scored by percent correct (although confidence level is an option for comparison with other tests). Earlier versions of this test have been administered to children 5 yr of age and older under different research protocols (Eisenberg et al, 2000; Uchanski et al, 2002).

Phoneme and Word Recognition

The ability to recognize words is accompanied by a growing repertoire of phonemes, vocabulary, and motor speech skills, plus the ability to use contextual information (linguistic, social, and situational). Behavioral measures of word recognition are typically introduced when a child is 3 to 4 yr of age. For our progressive test battery, we incorporated the following measures.

AB Isophonemic Word Lists—Phoneme recognition is assessed using the AB Isophonemic Word Lists (Boothroyd, 1968). A software program called Computer-Assisted Speech Perception Assessment (CASPA) (Mackersie et al, 2001) has been produced for ease of delivery, scoring, and analysis. CASPA delivers 20 sets of 10 CVC words. Within each set there is one instance each of 10 vowels and 20 consonants. The lists are intended to be scored phonemically, which minimizes the contributions of vocabulary knowledge and reduces confidence limits relative to the more traditional whole-word scoring. The test is appropriate for children 5 yr of age and older (McCreery et al, 2010).

Lexical Sentence Test (LEXSEN)—Recognition of words in isolation and words in sentences is measured using the Lexical Sentence Test (Eisenberg et al, 2002), or LEXSEN. Building on concepts from the Neighborhood Activation Model (Luce and Pisoni, 1998) and the Lexical Neighborhood Test (Kirk et al, 1995), a sentence test was developed that classifies target words from young normal-hearing children's vocabulary according to frequency of occurrence and acoustic-phonetic similarity. Lexically easy words are those that are high in frequency of occurrence but low in acoustic-phonetic similarity. Lexically hard words are those low in frequency of occurrence but high in acoustic-phonetic similarity. Thus, this test provides potentially useful information about the child's sensitivity to word frequency, lexical density, and sentence context. Early results with children who use cochlear implants demonstrated that lexically easy words were recognized with greater accuracy than lexically hard words, although the gap narrowed when the words were presented in sentences (Eisenberg et al, 2002). For convenience, the software program LEXSEN has been developed for delivery of stimulus, scoring, and analysis. Children with normal hearing 5 yr of age and older have been assessed on this measure. Notably, these stimuli have been used in other studies (Pisoni et al, 2008; Krull et al, 2010) and developed for use in multimodal application (Kirk et al, 2007; Holt et al, 2011).

Performance across Several Test Measures by Children with Hearing Loss

One of the goals of this study has been to conduct longitudinal speech perception testing across measures. Figure 3 displays results for three children with hearing loss who were assessed on two or more tests from the progressive test battery as a function of age (in years). The tests include OLIMSPAC, VIDSPAC, CASPA phonemes, LEXSEN words in isolation, and LEXSEN words in sentences. HI1 (top panel) is a cochlear implant user. The OLIMSPAC composite score reaches 80% at 4.5 yr. Scores for the more linguistically challenging materials differ substantially for this child. LEXSEN words in sentences yield the highest score and are recognized with greater accuracy than LEXSEN words in isolation. Both of the LEXSEN scores are recognized more accurately than CASPA words. It is worth pointing out that this child was younger than 5 yr of age when administered the word tests.

HI2 (middle panel) is a hearing aid user who achieves relatively high scores (70–85%) on the OLIMSPAC, approaching ceiling near 5 yr of age. Notably, the composite score achieved on VIDSPAC is equivalent to that of OLIMSPAC by about 4 yr of age. Scores on CASPA words and LEXSEN words (in isolation and in sentences) are either at ceiling or close to it at age 5 yr.

HI3 was originally a bilateral hearing aid user but eventually received a cochlear implant in one ear while continuing to use the hearing aid in the other ear. With bilateral hearing aids, HI3 improves substantially on OLIMSPAC between 4.5 and 5.5 yr of age, eventually reaching ceiling. With the hearing aid and cochlear implant combined, scores reach 100% for OLIMSPAC, VIDSPAC, CASPA, and LEXSEN by about age 6.5 yr.

Variability in performance on behavioral tests of speech perception is always problematic when testing young children of different ages and degrees of hearing loss, even when

attempting to control for age effects. The most difficult age we encountered has been 2 to 3 yr, and none of the tests in the progressive battery can consistently be administered to children of these ages. Piloting has commenced to explore new approaches to the behavioral assessment of auditory capacity specifically for children within the difficult age range. Electro-physiological cortical measures of speech contrasts also are being piloted as a more direct and potentially more valid means to track auditory capacity in young children with hearing loss.

CONCLUSION

Three projects have been described that address clinical concerns specific to pediatric hearing loss. The three projects are similar in that they explore the ways in which the factors of maturation and hearing loss interact. Two of the projects, CDaCI and DABCHL, utilize a “whole child” approach to examine performance outcomes across different developmental domains. We only report the speech recognition component of the CDaCI article. The third project, Assessing Auditory Capacity in Hearing-Impaired Children, emphasizes test development and evaluation of speech perception for infants and young children. The most recent study, DABCHL, has benefitted from this test development; VRASPAC and PLAYSPAC are incorporated into the speech perception test battery of this study. The SRI-Q, developed for the CDaCI study, also has broader application as illustrated in Figure 2 with two ABI children.

On a final note, the model we have adopted for conducting pediatric clinical studies integrates research and clinical personnel within the CARE Center. This model promotes bidirectional input between researchers and clinicians, interdisciplinary participation, and a strong sense of collaboration.

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Abbreviations

AO	auditory-only
AV	auditory-visual
CASPA	Computer-Assisted Speech Perception Assessment
CDaCI	Childhood Development after Cochlear Implantation
DABCHL	Development and Adaptive Behavior of Young Children with Hearing Loss
ESP	Early Speech Perception test
LEXSEN	Lexical Sentence Test

OLIMSPAC	On-line Version of an Imitative Test of Speech Pattern Contrast Perception
PLAYSPAC	Play Assessment of Speech Pattern Contrasts
SRI-Q	Speech Recognition Index in Quiet
VCV	vowel-consonant-vowel
VIDSPAC	Video-Game Speech-Pattern Contrast Test
VRASPAC	Visual Reinforcement Assessment of the Perception of Speech Pattern Contrasts

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Figure 1.

Mean trajectories for skill growth at baseline (*left panel*) and 3 yr (*right panel*) for children with cochlear implants (solid black line, filled circle symbols) and children with normal hearing (dashed black line, open box symbols). Adapted from Eisenberg et al (2010) with permission from Phonak AG.

Figure 2.

SRI-Q results for two children with auditory brainstem implants (ABI) compared with data from the CDaCI study. Displayed are individual data points for children with cochlear implants (solid black line, filled circle symbols) and their normal-hearing peers (dashed black line, open box symbols) assessed at the 2 yr (left panel) and 3 yr (right panel) test intervals. SRI-Q results at 2 yr are displayed for two children with auditory brainstem implants (ABI-2 and ABI-3) and at 3 yr for one child (ABI-2), represented by asterisks.

Figure 3.

Percent-correct results on three children with hearing loss assessed on the following measures as a function of age: OLIMSPAC, VIDSPAC, CASPA words, and LEXSEN words presented in isolation and in sentences. HI1 is a cochlear implant user. HI2 is a hearing aid user. HI3 was initially tested with hearing aids bilaterally but later received a cochlear implant in one ear and continued to use the hearing aid in the other ear.

Table 1**CDaCI Speech Recognition Hierarchy**

Parent Report	
Test	Stimulus
Infant-Toddler Meaningful Auditory Integration Scale (IT-MAIS) (Zimmerman-Phillips et al, 2000)	10 probes
Meaningful Auditory Integration Scale (MAIS) (Robbins et al, 1991)	10 probes
Closed-Set	
Test	Stimulus
Early Speech Perception (ESP)–Low Verbal (Moog and Geers, 1990)	spondaic and monosyllabic words
Early Speech Perception (ESP)–Standard Version (Moog and Geers, 1990)	spondaic and monosyllabic words
Pediatric Speech Intelligibility Test (PSI) (Jerger et al, 1980)	words and sentences in quiet and competition
Open-Set	
Test	Stimulus
Multisyllabic Lexical Neighborhood Test (MLNT) (Kirk et al, 1995)	multisyllabic words
Lexical Neighborhood Test (Kirk et al, 1995)	monosyllabic words
Phonetically Balanced Kindergarten word list (PBK) (Haskins, 1949)	monosyllabic words
Hearing in Noise Test for Children (HINT-C) (Nilsson et al, 1996)	sentences in quiet and noise

Source: Eisenberg et al, 2006.

Table 2

Developmental Outcomes from the DABCHL Study

	Normal Hearing (NH)	Hard of Hearing (HH)	
Participants (male, female)	28m, 29f	11m, 9f	
Mean age in months (SD)	17.8 (10.2)	21.6 (15.5)	
Measure	Mean (SD)	Mean (SD)	p-value
Mullen Scales of Early Learning (MSEL)			
Gross Motor T-score *	50.2 (12.1) *	44.3 (13.26) *	.085 *
Visual Reception T-score	55.9 (11.4)	51.4 (11.2)	.141
Fine Motor T-score	55.3 (9.4)	48.5 (11.8)	.024
Receptive Language T-score	46.7 (9.6)	41.7 (7.4)	.018
Expressive Language T-score	50.9 (12.4)	45.7 (7.7)	.030
Early Learning Composite Standard Score	104.5 (15.7)	94.3 (12.4)	.008
Preschool Language Scale-4th Edition (PLS-4)			
Auditory Comprehension standard score	98.8 (14.5)	95.6 (10.4)	.364
Expressive Communication standard score	107.6 (11.9)	101.5 (12.8)	.056
Total Language standard score	103.5 (13.7)	98.4 (11.5)	.136
Vineland Adaptive Behavior Scales-II (Vineland-II)			
Communication Domain standard score	100.6 (10.6)	97.6 (10.3)	.241
Daily Living Skills Domain standard score	93.7 (9.5)	90.4 (9.4)	.146
Socialization Domain standard score	94.7 (8.2)	91.8 (8.6)	.219
Motor Skills Domain standard score	98.3 (10.8)	94.7 (11.4)	.310
Adaptive Behavior Composite standard score	95.9 (8.0)	92.1 (8.9)	.107
Infant-Toddler Social and Emotional Assessment (ITSEA)			
Externalizing Domain T-score	46.8 (9.3)	48.7 (7.3)	.492
Internalizing Domain T-score	46.9 (10.7)	41.8 (7.5)	.066
Dysregulation Domain T-score	43.7 (14.2)	40.3 (9.2)	.941
Competence T-score	45.5 (8.9)	45.3 (11.4)	.479

Source: Stika et al, 2011.

* The Gross Motor subscale for MSEL is administered only to children <36 mo of age. Thus, analysis of this subscale was conducted on the subset of children who met this criterion and was not included in the overall analysis.