Pediatric Minimum Speech Test Battery

Article *in* Journal of the American Academy of Audiology · March 2017

DOI: 10.3766/jaaa.15123

4 authors, including:

Andrea D Warner-Czyz
University of Texas at Dallas

René H Gifford
Vanderbilt University

J Am Acad Audiol 28:232–247 (2017)

Tutorial

Pediatric Minimum Speech Test Battery

DOI: 10.3766/jaaa.15123

Kristin Uhler*
Andrea Warner-Czyz†
Rene Gifford‡
PMSTB Working Group§

Abstract

Background: Assessment of patient outcomes and documentation of treatment efficacy serves as an essential component of (re)habilitative audiology; however, no standardized protocol exists for the assessment of speech perception abilities for children with hearing loss. This presents a significant challenge in tracking performance of children who utilize various hearing technologies for within-subjects assessment, between-subjects assessment, and even across different facilities.

Purpose: The adoption and adherence to a standardized assessment protocol could help facilitate continuity of care, assist in clinical decision making, allow clinicians and researchers to define benchmarks for an aggregate clinical population, and in time, aid with patient counseling regarding expectations and predictions regarding longitudinal outcomes.

Design: The Pediatric Minimum Speech Test Battery (PMSTB) working group—comprised of clinicians, scientists, and industry representatives—commenced in 2012 and has worked collaboratively to construct the first PMSTB, which is described here.

Conclusions: Implementation of the PMSTB in clinical practice and dissemination of associated data are both critical for achieving the next level of success for children with hearing loss and for elevating pediatric hearing health care ensuring evidence-based practice for (re)habilitative audiology.

Key Words: auditory rehabilitation, cochlear implants, hearing aids and assistive listening devices, pediatric audiology, speech perception

Abbreviations: BAI = bone-anchored implants; BKB = Bamford–Kowal–Bench; CDaCI = Childhood Development after Cochlear Implantation; CI = cochlear implant; CNC = consonant-nucleus-consonant; ESP = Early Speech Perception; FM = frequency modulation; HA = hearing aid; LNT = Lexical Neighborhood Test; LOCHI = Longitudinal Outcomes of Children with Hearing Impairment; MLV = monitored live voice; OCHL = Outcomes of Children with Hearing Loss study; PMSTB = Pediatric Minimum Speech Test Battery; PSI = Pediatric Sentence Intelligibility; VRISD = visual reinforcement infant speech discrimination

INTRODUCTION

Nearly 5 yr ago, Uhler and Gifford (2014) conducted a nationwide survey of pediatric audiologists in an attempt to characterize common clinical practices and protocols. This survey was distributed to 700 audiologists attending the 2012 American Cochlear Implant Alliance meeting via a pencil-and-paper questionnaire as well as to 375 audiologists via Research Electronic Data Capture (Harris et al, 2009). Results revealed a wide variety of tests, implementations, and protocols across facilities, highlighting the need to standardize a speech test battery to monitor outcomes in children with hearing loss. Uhler and Gifford (2014) presented these results at the 2013 AAA AudiologyNow! Conference in Anaheim, CA, and later that year at the 2013 American Cochlear Implant Alliance symposium in Washington, DC. Attendees at these meetings plus the

*University of Colorado Denver School of Medicine, Aurora, CO; †The University of Texas at Dallas, Dallas, TX; ‡Vanderbilt University, Nashville, TN; §A complete list of the PMSTB Working Group members appears on page 245.

Corresponding author: Rene Gifford, Vanderbilt University, Nashville, TN 37232; E-mail: rene.h.gifford@Vanderbilt.edu

original 375 pediatric audiologists emailed in 2012 were again invited to participate, via Research Electronic Data Capture, in the development of a standardized test battery. The result of these efforts was the Pediatric Minimum Speech Test Battery (PMSTB) working group. This working group was comprised of a heterogeneous group of academic, clinical, research, and industry professionals—all with pediatric audiology experience—determined to find consensus on best practices for the assessment of speech understanding in children with hearing loss. The underlying goal of this working group was to develop and disseminate a consensus document that would be both data driven and aligned with current clinical practices (i.e., avoiding research tools not validated in large clinical populations). Therefore, this PMSTB embodies the three cornerstones of evidence-based practice: research, clinical expertise, and patient/family concerns.

The PMSTB working group held two conference calls (November 22, 2013, and March 21, 2014) and created a publicly available wiki page to post meeting minutes and share center protocols (https://sites.google.com/site/pediatricmstbworkinggroup/home). During these conference calls, the working group members were encouraged to recruit additional colleagues for participation and to provide feedback on the materials under development. Once the pediatric working group agreed upon a protocol on March 21, 2014, the primary authors wrote the manual, posted it on the project wiki, and requested further feedback. Thus, this first implemented version of the PMSTB integrated feedback from scientists, clinicians, and industry professionals, resulting in the manual presented in Supplemental Appendix S1, supplemental to the online version of this article.

There were numerous factors motivating the development of the PMSTB including the potential scientific and clinical benefits afforded by a standardized PMSTB as well as our professional obligation to monitor a child's auditory progress and to maximize his or her auditory potential. The PMSTB battery includes measures designed to evaluate speech discrimination for infants and word/sentence recognition for children using hearing technology before entering school (Appendix A). Please note that the PMSTB emphasizes the use of developmentally appropriate measures consistent with a child's language skills before school entry. At any time that a child's skills demonstrate readiness to transition to a more challenging measure than those included here, clinicians are encouraged to consider the adult Minimum Speech Test Battery (MSTB, 2011).

As stated above, no standardized protocol currently exists to assess speech perception abilities for children with hearing loss. This presents a significant challenge in tracking performance of children who use various hearing technologies (e.g., hearing aids [HA], cochlear implants [CIs], osseointegrated devices, frequency modulation [FM], or digital modulation technology) within the same child, across different children, and across different facilities. Children with hearing loss represent a heterogeneous population, making the generalization of outcomes a challenge. For this reason, large sample sizes are essential to establishing consistent and standardized reporting of outcomes and to address the variance in performance. Studies completed at single sites in both HA (e.g., Stelmachowicz et al, 2010; Leibold et al, 2013; Hillock-Dunn et al, 2014; McCreery et al, 2014; Hillock-Dunn et al, 2015) and CI users (e.g., Desai et al, 2008; Sarant et al, 2009) provide highly valuable information contributing to the body of knowledge in our field; however, variability in study protocols (i.e., assessment measures, presentation levels, presentation method, sampled ages) across the different studies/centers compromises generalization to the larger clinical population.

Transitioning to a uniform test battery, similar to the adult MSTB (2011), can afford greater consistency in testing as well as greater ability to pool data and generalize findings. Specifically, the PMSTB may help accomplish several large-scale goals, as outlined below:

1. Setting guidelines and performance level across sites. The development and implementation of a uniform test battery can foster collaboration and compilation of information across individual centers. A standardized test battery would provide a much-needed guideline for the assessment of speech perception abilities in infants and young children in both the clinic and the research laboratory. For example, implementation of this battery and subsequent publication of outcome data for the same measures across multiple centers and research teams will provide us with valuable age normative data for various degrees of hearing loss, ages, and interventions. Availability of these normative data in the peer-reviewed literature will allow us to track progress of our own patient population for a given center as well as afford comparison across institutions, interventions, educational approaches, and other patient-specific variables not currently possible.
2. Setting realistic expectations for families. The widespread adoption of a standardized test battery will yield outcomes that can facilitate family counseling regarding realistic expectations for speech perception abilities.

    a. Establishing expected outcomes allows comparison by chronologic age, device experience, developmental age, language ability, hearing modality (e.g., unilateral versus bilateral versus. bimodal), etc. to identify children not meeting expected benchmarks.
    b. A standardized test battery addressing the evaluation of "all children with hearing loss"—including children with secondary disabilities—will provide us with the necessary information to identify children who may require additional services and

intervention. Many studies exclude children with secondary disabilities, a group that constitutes 15–47% (Eze et al, 2013; Inscoe and Bones, 2016) of children with hearing loss (Yoshinaga-Itano et al, 1998). Excluding these children from assessment in both the clinic and research laboratory works as a disservice to the field in two ways. First, some children with secondary issues can complete speech perception tasks. For example, Eshraghi et al (2015) found that two-thirds of children with autism spectrum disorder using CIs can at least identify or recognize simple phrases, an early-developing auditory skill, per parent report. Second, eliminating children with secondary disabilities from research studies hinders our ability as clinicians to identify suitable expectations and appropriate recommendations for supplemental technology (such as home FM use) and outcomes assessment in these children. However, implementing a standardized PMSTB will allow specification of expected progress based not only on presence or absence of additional special needs, but also (eventually) expected progress by specific type of additional special needs (e.g., autism, cerebral palsy).

3. Guiding clinical decision-making. Availability and use of a standardized test battery can provide great value in clinical decision-making regarding the need for additional CI and/or HA programming, assistive technology (FM or DM), bilateral CI candidacy, or some combination thereof. Establishment of standardized measures to evaluate children with hearing loss will allow clinicians and researchers to evaluate markers for on-target versus slower progress. For example, inability to perform within one standard deviation of peers with similar degree of hearing loss may indicate time for a change in technology or recommended therapy to optimize a child's outcomes.
4. Supporting a database registry of children with hearing loss. There has been considerable discussion among professionals and policymakers regarding the move toward a national or international registry of CI recipient outcomes—something already in place for CI recipients in France and Switzerland (Brand et al, 2014) and in the process of development for adult CI recipients in the United States (Centers for Medicare and Medicaid Services, 2004). Having a standardized battery for pediatric speech perception is of critical importance if we are to work toward this goal. The purposes for a national registry of any given intervention or etiology include

   a. elevation of clinical practice through standardized protocols and assessment batteries;
   b. implementation of evidence-based practice and the subsequent study of the outcomes on an aggregate population;
   c. verification and validation of the recommended treatment (in this case, cochlear implantation); and
   d. development of a virtual network of clinicians and researchers allowing for a free exchange of data and experience. In the absence of a standardized assessment battery, implementation of a data registry would be essentially useless as it would be nearly impossible to summarize the effectiveness of a particular intervention and to pool data across sites and even across clinicians within a given institution.

The adoption of the PMSTB with a hierarchical protocol will allow for consistency of assessment methods across clinicians and sites. As mentioned above, this alone will facilitate the collection and dissemination of large-scale normative datasets and auditory milestones for common speech recognition metrics administered to children with hearing loss (Uhler and Gifford, 2014). While the release of the PMSTB will not automatically result in multicenter studies nor in the development of a pediatric registry, without it, such endeavors would be nearly impossible. Using the adult CI population as a comparison, since the release of the adult MSTB in 2011, researchers have published 11 peer-reviewed papers describing outcomes for adult CI recipients using AzBio sentence lists (Dorman et al, 2012; Gifford et al, 2014; Koch et al, 2014; Mahmoud and Ruckenstein, 2014; Massa and Ruckenstein, 2014; Dorman et al, 2015; Wolfe et al, 2015; Beyea et al, 2016; Olds et al, 2016; Roland et al, 2016; Runge et al, 2016). These 11 papers all included "at least" 30 participants with CIs (M = 69 participants; range 32–125) and met classification criteria as a Quality-B or higher study per the quality assessment grading metrics employed by the Agency for Healthcare Research and Quality Methods Guide for Comparative Effectiveness Reviews (AHRQ, 2011; 2014). Only two peer-reviewed publications meeting these criteria existed before the release of the adult MSTB in 2011 (Spahr et al, 2007; Gifford et al, 2008). Thus, historical precedent in the peer-reviewed literature supports the adoption of a uniform test battery and the subsequent dissemination of associated data.

HISTORICAL PERSPECTIVE ON THE DEVELOPMENT OF A STANDARDIZED TEST BATTERY

This working group is not the first to attempt construction of a standardized and uniform test battery for assessing speech understanding in the pediatric audiology clinic. Historically, several have attempted to develop a standardized test battery for use with pediatric CI recipients (Tyler et al, 1986; 1987; Eisenberg et al, 2006). During the US investigation of the safety and efficacy of pediatric cochlear implantation in the 1980s, several published reports described the types of speech perception metrics recommended for use in this population. Though a detailed protocol outlining "specific measures" was neither recommended nor universally adopted, these pioneering efforts resulted in an agreement regarding the "minimal acceptable characteristics" of the stimuli included in such a battery. Those characteristics include

a. an ability to gauge conversational abilities;
b. a capacity to meet developmental language and cognitive abilities of the child;
c. consistency of testing (i.e., high test–retest reliability);
d. availability of multiple equivalent lists to avoid familiarity of test materials;
e. standardization of recordings to avoid monitored live voice (MLV) presentation; and
f. a variety of measures (e.g., words, sentences, nonlinguistic; Tyler et al, 1986; 1987; Waltzman et al, 1990; Osberger et al, 1991).

Other researchers have also developed a hierarchical protocol for assessing speech recognition abilities in children with hearing loss. The Childhood Development after Cochlear Implantation (CDaCI) investigative team launched the first longitudinal multicenter investigation of various outcomes following pediatric cochlear implantation (Eisenberg et al, 2006; Fink et al, 2007; Niparko et al, 2010). The CDaCI investigative team defined a uniform hierarchical protocol to meet the minimum requirements listed above for a chosen set of speech perception measures. The PMSTB protocol in this manuscript builds on concepts initiated by the CDaCI Investigative team by incorporating measures more commonly used in audiology clinics and newly developed and validated materials (e.g., Pediatric AzBio) that have emerged since the CDaCI project officially launched in early 2001.

The PMSTB introduces measures in a hierarchical organization of task difficulty allowing us to track a child's progress over time—similar to its predecessors such as the CDaCI study protocol (Eisenberg et al, 2006; Wang et al, 2008; Niparko et al, 2010), the Longitudinal Outcomes of Children with Hearing Impairment (LOCHI; Ching et al, 2013) and the Outcomes of Children with Hearing Loss study (OCHL; Tomblin et al, 2014; 2015 McCreery et al, 2015). Table 1 summarizes the

Table 1. Rationale for Test Selection

Tests Selected	Open or Closed Set	Stimulus	Listening Condition	Norming Population	Pros	Cons
VRISD	Closed	Syllable	Quiet	Normal hearing	Independent of language abilities	Requires conditioned head turn; norms required for additional contrasts
ESP, Low Verbal or Standard	Closed	Word	Quiet	Hearing loss	Assesses an array of speech discrimination abilities	Toys can be distracting
PSI	Closed	Word, sentence	Quiet and noise	Normal hearing and hearing loss	Can be done in presence of semantic distractor	Limited number of lists
MLNT/LNT	Open	Word	Quiet	N/A	Familiar words for children with limited vocabulary, lists with varying lexical difficulty	Limited number of lists, norms needed
CNC	Open	Word	Quiet	N/A	Use of prompt "ready," included in adult MSTB	50-word list is most reliable, child may need breaks
BKB	Open	Sentence	Quiet	N/A	Use of prompt "ready," low context for younger children	Norms not available for children younger than 5 yr
BKB in SIN	Open	Sentence	Noise	Normal hearing	Adaptive test, norms across life span	Norms not available for children younger than 5 yr (Schafer, 2010)
Pediatric AzBio (BabyBio)	Open	Sentence	Quiet and noise	Normal hearing	Norms for children 5–12 yr, equivalent lists	16 lists, female talker only

Notes: Tests selected by the PMSTB working group. This table describes whether the tests are open or closed set, stimulus type and the listening conditions that can be assessed, norming population, as well as pros and cons for each test. LNT = Lexical Neighborhood Test; MLNT = Multisyllabic Lexical Neighborhood Test; N/A = not applicable; SIN = Speech-in-Noise.

speech perception measures selected for the PMSTB. Selected measures were restricted to those that were both clinically available for purchase as well as validated at the time of PMSTB consensus (2013–2015). Many of the measures included in the PMSTB are consistent with measures used in larger pediatric research studies (e.g., CDACI study [Eisenberg et al, 2006; Wang et al, 2008; Niparko et al, 2010], LOCHI study [Ching et al, 2013], OCHL study [McCreery et al, 2015]). As with all three established protocols (CDaCI, LOCHI, and OCHL), the proposed PMSTB also incorporates parent questionnaires to address outcomes in a preverbal population rather than to assess speech perception. Therefore, we provide a more thorough description regarding appropriate populations and implementation of questionnaires in Supplemental Appendix S1.

This first iteration of the PMSTB focuses on infants and young children before school entrance at the age of 5 yr or a language equivalent of 5 yr. The working group encourages the administration of multiple types of tests (e.g., word and sentence measures) per testing session, but recognizes that attaining a complete battery will likely require multiple sessions. Thus, the speech perception data obtained from this hierarchical PMSTB protocol will evolve over time as the child's developmental and language abilities mature. Additionally, we recognize that some of the PMSTB measures may have a limited number of validated lists, in some cases precluding assessment of all listening conditions in a single test session. For this reason, the PMSTB working group fully supports the development and subsequent validation of additional measures for assessment of speech understanding in preschool- and school-aged populations as well as future modifications to the measures recommended in the PMSTB hierarchy.

The PMSTB guidelines, summarized in Table 2 of Supplemental Appendix S1, highlight testing at multiple intensities (i.e., conversational speech level in quiet [60 dBA], conversational speech level in noise [65 dBA], soft speech level [50 dBA]) in multiple listening environments (i.e., quiet, noise, +5 dB SNR) using a ranked array of speech stimuli (i.e., phonemes, words, and sentences). Multiple studies have assessed outcomes for individuals with hearing loss at these levels, both in quiet and in noise (adults "soft speech levels": Skinner et al, 1999; Firszt et al, 2004; Dwyer et al, 2016; children "soft speech levels": Davidson, 2006; Davidson et al, 2009; Baudhuin et al, 2012; Robinson et al, 2012; Geers et al, 2013; children +5 dB SNR: Gifford et al, 2011; Sheffield et al, 2015; children both at high and low levels: Rakszawski et al, 2016). Thus, these recommendations are data driven and include stimuli and presentation levels for which feasibility has been documented.

As mentioned previously, this working group aimed to develop a suggested protocol using "currently commercially available" measures rather than to develop new tests. The group selected tests for this battery based on availability, clinical acceptance, ease of administration, availability of normative data for children with normal hearing and/or hearing loss, group consensus, and the ability to transition to a more age- and language-appropriate battery as necessary for each child. Specifically, once the child has reached the ceiling performance levels for tests in this battery, it is expected that the audiologist will transition to those measures outlined in the adult MSTB (MSTB, 2011). (It should be noted that one test recommended for the PMSTB, a conditioned head turn task similar to visual reinforcement audiometry called visual reinforcement infant speech discrimination [VRISD], does not have widespread clinical use at this time. However, centers can purchase VRISD commercially to assess infant discrimination. Multiple centers have implemented VRISD as a discrimination metric both in clinic [Govaerts et al 2006; 2010; Uhler et al, 2011; Uhler, 2014] and in research [Moore et al, 1975; Eilers et al, 1977; Nozza, 1987; Martinez et al, 2008; Uhler et al, 2011; Uhler et al, 2015]. Please see Supplemental Appendix S1 for further details.)

RATIONALE FOR TEST SELECTION

The design of the PMSTB battery matches Kirk and colleagues' (2009) description of a comprehensive battery, which "should permit the evaluation of a hierarchy of skills, ranging from discrimination of vowel and consonant speech features through the comprehension of connected speech" (p. 225). Successful implementation of a test battery depends on the clinician's ability to understand how to administer the assessment measures and when to administer and/or stop administering particular instruments. This decision must be both easily and quickly executable within a test session.

The PMSTB manual describes the test battery, illustrated as a flowchart in Figure A1 in Supplemental Appendix S1, and provides information on the administration of particular tests as well as guidelines for transitioning between measures of higher or lower difficulty for a particular child (see Appendix B for ordering details). The following sections describe subtleties associated with selection of a test relative to a child's ability to respond, language age, articulation abilities, and current auditory skills.

Select Measures That Match the Child's Ability to Respond

To make the PMSTB relevant for a broad age range including infants, preschoolers, and potentially early school-aged children, the current iteration includes parent questionnaires as well as closed- and open-set measures of speech understanding. Parent questionnaires provide a glimpse into a child's performance in a real-world environment and supply information for children who cannot complete behavioral measures due to chronological age or developmental level. The parent questionnaires selected for the PMSTB include LittlEARS (Kuehn-Inacken et al, 2003; Coninx et al, 2009) and the Auditory Skills Checklist (Meinzen-Derr et al, 2007). The manual describes the purpose, administration, and scoring of both instruments.

Closed-set tests limit response options to a predetermined, fixed array of items. For example, children can select a response to an auditory stimulus from 1 of 4 tangible items on the Early Speech Perception (ESP) Low Verbal version, 1 of 5 images on the Pediatric Sentence Intelligibility (PSI) test, or 1 of 12 pictures on the ESP Standard Version test (Jerger et al, 1983; Moog and Geers, 1990). The level of difficulty increases with a greater number of items in the foil. Children with normal hearing often can complete the aforementioned closed-set tests by 3 yr of age (Robbins and Kirk, 1996). Children in this age range, who typically exhibit greater receptive versus expressive language, can easily respond via pointing to pictures of objects. The restriction of potential response options in closed-set tests may not necessarily represent real-world listening situations, but it does provide several advantages. First, closed-set tests pose an easier task that young children can complete based on their language and motor abilities. Second, closed-set tests allow children to focus on audition with reductions in the concomitant influence of cognitive-linguistic factors (i.e., expressive and receptive vocabulary, auditory memory) relative to open-set tasks (Boothroyd 1995; Eisenberg et al, 2003; 2004). Thus, closed-set tests afford a first glimpse into how a child attaches meaning to sound in a structured manner.

On the other hand, open-set speech perception tests do not limit response possibilities. Children can answer via verbal, gestural, or signed response to word (e.g., "banana, water, please") or sentence stimuli (e.g., "The baby monkey swings from the trees"). Examples of pediatric open-set speech perception tests include the Multisyllabic Lexical Neighborhood Test (Kirk, Pisoni, and Osberger, 1995), Lexical Neighborhood Test (LNT; Kirk et al, 1995), the Bamford–Kowal–Bench (BKB) Sentence-in-Noise test (Etymōtic Research, Inc., 2005; also see Bench et al, 1979), and the Pediatric AzBio test (BabyBio; Spahr et al, 2014). Open-set tests have greater real-world application because they do not constrain topics by including pictures or objects to guide attention. Rather, words and sentences that could occur in real conversations may include a wide array of subject areas, organization structure, or key words (Tyler et al, 1986; 1987).

Select Measures That Match the Child's Language Age, Not Chronologic Age

Most tests in the present protocol provide recommended age ranges based on typical development; however, note that the recommended age ranges in the PMSTB may differ slightly from those recommended by the test manuals. These decisions stemmed not only from typical development, but also the breadth and depth of clinical experience represented by the PMSTB working group. Thus, the working group's recommendations regarding appropriate age ranges should serve as a flexible starting point, remaining mindful of the wide range in language skill levels for children with and without hearing loss.

Children with hearing loss may acquire speech and language skills differently than their peers with normal hearing. As clinical audiologists, we need to exhibit sensitivity to differences in language abilities and not focus solely on chronologic age as a criterion for selection and administration of speech perception tests. This highlighted need for sensitivity comes from the fact that children with hearing loss demonstrate difficulties acquiring not only speech perception skills but also speech production accuracy and receptive and expressive language abilities (Boothroyd et al, 1991; Hayes et al, 2009; Tobey et al, 2011).

Clinicians are better equipped to select an appropriate test when provided with information about the global developmental level and language abilities of a child with hearing loss. For example, an infant who receives a CI at 12 mo of age may not utter his first word until 5–10 mo after CI activation, at a chronologic age of 17–22 mo (Warner-Czyz and Davis, 2008). Typically developing hearing peers at the same chronologic age have a much different communication skill set. In infants with typical hearing, first spoken words emerge ~12 mo of age and the number of new words increases at a slow rate (i.e., 1–3 new words per month) until a "vocabulary spurt," in which word acquisition increases significantly (i.e., 10–20 new words per week) ~21 mo of age (Ganger and Brent, 2004). This vocabulary spurt reflects the repetition of words over time, variation in word difficulty over time, and the child's efficiency to learn new words (Hart and Risley, 1995; McMurray, 2007). Thus, an average 21-mo-old with normal hearing may have a lexicon of nearly 200 words (median = 171 words), whereas a 21-mo-old with a CI may have just 5 spoken words (<5th percentile; Fenson et al, 2007). Clinicians can use knowledge of a child's language level based on parent report and language assessment reports from a speech-language pathologist to select appropriate speech perception tests.

Children using HAs also increase receptive and expressive vocabulary skills over time, but the rate of word acquisition does not always match that of typically developing peers—especially for those with more severe degrees of hearing loss. Mayne, Yoshinaga-Itano, Sedey (2000) reported that infants and toddlers using HAs understand an average of 14 words between 8 and 10 mo, and 47 words between 14 and 16 mo. These values lag behind the lexicon size of hearing peers, who have median receptive vocabularies of 24–45 words and 126–192 words, respectively—thereby indicating that the receptive vocabulary of children using HAs corresponds more closely to the 5th–10th percentile performance levels at similar ages (Fenson et al, 2007). However, a more recent study by Moeller, Hoover, Putman, Arbataitis, Bohnenkamp, Peterson, Wood, et al (2007) showed a main effect of age (10–24 mo) but not auditory status on receptive language outcomes in children with HAs.

Differences in lexicon size in toddlers with hearing loss versus those with normal hearing also persist in expressive vocabulary. Median vocabulary size of pediatric HA users increases from 0 to 31 words from 8 to 25 mo (Mayne, Yoshinaga-Itano, Sedey, Carey, 2000). These values fall behind median values reported in 24-mo-old, typically developing children (251–344 words), instead matching a lower percentile score (35th) for chronologically younger children (16 mo; Fenson et al, 2007). Percentile scores for both receptive and expressive language of toddlers with HAs fall increasingly behind hearing peers, indicating a slower rate of acquisition in children with hearing loss—a phenomena termed "gap opening" (Moeller, Hoover, Putman, Arbataitis, Bohnenkamp, Peterson, Wood, et al, 2007; Yoshinaga-Itano et al, 2010). The majority of infants are identified and fit with amplification before 6 mo of age, but there continues to be a wide range at age of identification (0.25–60 mo) and fitting of amplification, even in a contemporary group of young children with hearing loss (1.5–72 mo; Holte et al, 2012); thus, clinicians also must consider a child's receptive and expressive vocabulary.

Even more recent studies of pediatric HA users confirm slower language development in children with mild-to-severe hearing loss relative to hearing peers (Ching et al, 2013; Tomblin et al, 2014; 2015). For example, Ching et al (2013) reported that 3-yr-old children with hearing loss obtained a mean global language score more than one standard deviation poorer than age-matched hearing counterparts. We should acknowledge, however, that children with hearing loss show considerable variability in development of receptive and expressive language skills based on demographic and environmental factors including, but not limited to the following: age at identification of hearing loss, severity of hearing loss, degree of audibility, age at HA fit (<18 mo), chronologic age, social interaction, presence of additional disabilities, and quality of linguistic input (Yoshinaga-Itano et al, 1998; Mayne, Yoshinaga-Itano, Sedey, 2000; Mayne, Yoshinaga-Itano, Sedey, Carey, 2000; Fulcher et al, 2012; Ching et al, 2013; Ambrose et al, 2014; Tomblin et al, 2015).

Recognizing differences in language performance levels as opposed to relying on chronologic age will aid in choosing an appropriate speech perception measure. Table 1 in Supplemental Appendix S1 integrates expected receptive and expressive language milestones by chronologic age with appropriate assessment tools for both language and speech perception. The inclusion of typical scores (e.g., 50th percentile) and normative score ranges based on chronologic age will allow clinicians to (a) interpret performance levels as assessed by speech-language pathologists, and (b) compare performance of a child with hearing loss to hearing peers of either the same chronologic age or same listening age. Knowing a child's language level also will facilitate selection of a suitable speech perception test in which a child can comprehend and participate in the testing process to the best of his or her abilities.

Consider Alternative Scoring Methods on Individual Tests

Differences in language abilities influence which test(s) a child can complete. Clinicians should pay attention to not only the child's language abilities, but also his or her speech production skills. Infants and toddlers with hearing loss often show delays in vocal developmental milestones such as the onset of babbling and first words relative to peers with normal hearing (Stoel-Gammon and Otomo, 1986; Oller and Eilers, 1988; Moeller, Hoover, Putman, Arbataitis, Bohnenkamp, Peterson, Lewis, et al, 2007). Phonetic inventories and production accuracy present another area of difference based on auditory status, but effects differ based on phonetic segment type and auditory technology. Infants and toddlers using HAs expand consonant repertoires more slowly than hearing peers—particularly relative to fricatives and affricates—but show no differences in vowel inventories (Kent et al, 1987; Yoshinaga-Itano and Sedey, 2000; Moeller, Hoover, Putman, Arbataitis, Bohnenkamp, Peterson, Lewis, et al, 2007). Matching speech production to word targets creates greater difficulty such that toddlers with normal hearing outperform those with HAs on consonant accuracy, presence of final consonants in words, and vowel accuracy (Moeller, Hoover, Putman, Arbataitis, Bohnenkamp, Peterson, Wood, et al, 2007). For example, it has been reported that children with congenital hearing loss are more likely to omit phonemes that are harder to hear such as /s/ and /z/ (Stelmachowicz et al, 2002; McGuckian and Henry, 2007; Koehlinger et al, 2013).

Children with CIs tend to exhibit greatest production accuracy for the sounds they produce most often (e.g., visible consonants such as /b/ and /m/ and neutral vowels such as /ʌ/ and /ə/) (Warner-Czyz and Davis, 2008). This population often experiences articulation difficulties for consonants classified as coronal (e.g., /t/), dorsal (e.g., /k/, /g/), or fricative (e.g., /s/, /ʃ/), and vowels produced in the back of the oral cavity (e.g., /u/, /o/) (Warner-Czyz and Davis, 2008; Warner-Czyz et al, 2010).

Mispronunciation of these sounds may or may not affect intelligibility by a naïve listener. Tobey and colleagues reported a moderate correlation ($r > 0.50$) between the percentage of vowels correct and speech intelligibility and a high correlation ($r > 0.80$) between the percentage of consonants correct and speech intelligibility (Tobey et al, 2003; Tobey et al, 2011; 2013). Specifically, stop-plosives ($r = 0.59$) and fricatives ($r = 0.79$) strongly correlate with intelligibility by a naïve listener (Tobey et al, 2003). Thus, incorrect articulation of stop-plosives (e.g., /t/, /k/, /g/) and fricatives affects speech intelligibility and could, thus, affect clinician ratings of speech perception.

Many of the more advanced speech perception tests use an open-set format, in which verbal responses have an infinite range. Scoring involves calculating a percent correct score at the phoneme, word, key word, or sentence level. However, these scores often build upon each other such that omitting one phoneme or syllable (e.g., /nænə/ for *banana*) affects not only the phoneme score, but also the word score if strict scoring requires accurate pronunciation of all phonemes to count as correct. The same concept arises for sentence scoring if the child must produce all key words to yield a correct sentence score. Thus, misarticulation—a speech production issue—inadvertently affects scores on multiple speech perception measures.

Clinicians should practice caution in penalizing children for misarticulation on a speech perception test. Appropriate follow-up based on speech perception scores depends on determination if errors relate to an underlying speech perception or speech production (articulation) issue. Device programing by an audiologist (Tyler et al, 1987) addresses a speech perception error, whereas therapeutic intervention by a speech-language pathologist is able to aid in determination of a true articulation error versus a developmentally appropriate error. For example, a common perceptual confusion for CI users is /u/ versus /m/ due to the frequency overlap of the first formant and difference in the second formant. However, this is not a common articulation error. Thus, the documentation and subsequent analysis of error patterns may inform both perceptual and production aspects of communication above and beyond a percent correct score.

Select Measures That Match the Child's Current Auditory Skills Level

One of our primary goals as clinicians and researchers focuses on assessing a child's perceptual skills as accurately as possible based on current auditory skills. The PMSTB provides guidance as to when clinicians should transition to a different test. For example, performance scores greater than 75–80% correct suggest a child has mastered the skills assessed in a particular test and should proceed to the next hierarchical level of difficulty, either in the same testing session or during the next testing session. On the other hand, scores of ~25% or lower suggest that a simpler task is necessary. The lower limit of this score range is based on chance for a four-choice test being 25% (Tomblin et al, 1999). Determining the upper criterion, however, was a more challenging task. The operational definition of a ceiling effect is the maximum possible score for a particular measure. If we were confident that all children with hearing loss could achieve 100% accuracy on each measure of speech perception, then we would have suggested that the clinician progress to the next level of difficulty once a child had achieved a score that was not significantly different from 100% (based on the 95% confidence interval for the chosen measure). Children with hearing loss, however, will likely not achieve a true ceiling effect on all measures, especially speech perception in noise. Thus, the PMSTB working group chose a value in the range of 75–80% to be approaching ceiling, as we expect many children will asymptote at scores <100%. More moderate performance scores (i.e., 25–79% correct) suggest emergence of skills assessed in that measure, thereby suggesting the appropriateness of the measure for continued use in future test sessions. Conversely, once scores reach 80% or higher "on a particular measure," the clinician should administer the next measure in the hierarchy—either at the same visit (pending child attention and fatigue) or at the next scheduled visit (e.g., transitioning from LNT words to consonant-nucleus-consonant [CNC] words). In this same scenario, regardless of whether the clinician transitions to CNC, the clinician would continue with the hierarchical protocol progressing from words to sentences in quiet and then to sentences in noise. Once a child has achieved mastery (≥80% correct) on the higher level auditory assessments (e.g., BabyBio), future testing can focus on more advanced speech perception tests included in the adult MSTB (e.g., AzBio).

Evaluators expect this forward progression in the acquisition of auditory perceptual skills. However, what happens when a child cannot achieve even 25% correct on a specific task? When a child cannot attain a minimal level of proficiency on a speech perception measure, the PMSTB recommends shifting to an easier perceptual task to meet the child at his or her level of auditory skills. For example, a child scoring <25% correct on the ESP monosyllable task—which presents stimuli differing in vowels only (e.g., "bat, boat, boot")—should not transition to PSI words, which require monosyllabic differentiation. Rather, that child should revert to the perceptually easier ESP spondee task, which presents two-syllable stimuli with differing consonant and vowel composition (e.g., "hotdog" and "bathtub").

Interpret Outcomes Relative to Other Tests and Previous Performance

Making clinical decisions requires professionals to look beyond test scores on an individual test measure. That is, to comprehensively assess a child's speech perception abilities, clinicians must consider performance across measures and performance across testing sessions. Clinical decision-making relies not only on absolute scores but also on relative values when comparing performance over time or with different device configurations. A clinician needs to know if a change in performance constitutes a "clinically significant change." The PMSTB manual provides the 95% confidence interval for test–retest variability on an individual level, by age and for the number of lists where these normative data are available (see Tables 9–11 in Supplemental Appendix S1). As mentioned previously, with the implementation of the PMSTB, we anticipate the collection and dissemination of normative data for each measure included in the current and future versions of the PMSTB.

A final fallback to an easier perceptual task is to revert from recorded materials to MLV. The protocol recommends recorded speech perception materials to maintain consistency of speaker intensity, dialect, and intonation, and to avoid the inflation of scores commonly observed with MLV (Roeser and Clark, 2008; Uhler et al, 2016). Though MLV affords greater flexibility in testing—particularly for very young children and individuals with reduced cognitive function—MLV reduces the reliability of test results, making it impossible to compare across test sessions and testers. Therefore, we recommend that MLV be avoided whenever possible.

Overall, test selection within the PMSTB offers flexibility in terms of starting point as well as forward and backward transition to match the speech perception testing needs of an individual child. Clinicians should pay attention to multiple details such as a child's ability to respond, language age, articulation, and current auditory skills when evaluating speech perception abilities of a child with hearing loss.

RATIONALE FOR PROTOCOL DESIGN: MULTIPLE LEVELS AND LISTENING CONFIGURATIONS

Assistive technology such as HAs and CIs can provide children with hearing loss the necessary auditory access to acquire listening and spoken language skills. The benefits of this technology, however, may depend on the stimulus level and listening environment. Thus it is essential that we consider multiple listening scenarios in order to optimize fittings for HA, CI, and bone-anchored implants (BAI). Testing at average conversational speech levels (e.g., 60 dBA) indicates how well a child will understand a talker positioned within a few feet. Testing at lower presentation levels approximating perceptual descriptions of "soft speech" (e.g., 50 dBA) mimics common listening conditions because children rarely have a consistently optimal signal, and perception of low-level speech has potential implications for receptive and expressive language development.

Children with normal hearing commonly acquire language abilities through incidental learning (Akhtar et al, 2001) and overall exposure to quality language (Hart and Risley, 1995; Landry et al, 2000; Huttenlocher et al, 2002; Kashinath et al, 2006; Law et al, 2009; Suskind et al, 2013). Thus, we can expect similar if not greater disparities in children with hearing loss, who not only have less exposure to language produced at lower intensity levels but also have compromised stimulus delivery.

Hearing Technology Verification and Validation

Regardless of auditory status, children learn language best not only when they have access to low-level speech, but also when they can access speech at various levels in adverse listening conditions—both of which can be optimized through well-fit devices (e.g., HAs, CIs, BAI, FM/DM) for children with hearing loss. Classrooms, playgrounds, and home environments represent typical listening situations for young children, and all yield an unfavorable signal-to-noise ratio in which children with hearing loss are expected to thrive (Sanders, 1965; Nober and Nober, 1975; Bess et al, 1984; Finitzo-Hieber, 1988; Clark and Govett, 1995; Crandell and Smaldino, 1995; Crukley et al, 2011). Thus, it follows that the evaluation of speech recognition in noise should be standard clinical practice for "validation" of HA and/or CI fittings following "verification" of acoustic ear canal SPL for HA, aided warbled-tone thresholds for CI, and verification of BAI output using a combination of audiometric thresholds obtained with direct bone conduction or measurement of processor output via coupling to a skull simulator. In summary, the stimulus presentation levels included in the PMSTB were chosen on the basis of (a) ecological validity as these represent average levels of speech and noise most frequently encountered in everyday listening environments for both pediatric and adult listeners (Pearsons et al, 1977; Clark and Govett, 1995; Olsen, 1998; Crukley et al, 2011; Smeds et al, 2015), and (b) feasibility documented in the peer-reviewed literature for presentation at levels ranging from 50 to 60 dBA in quiet and higher in the presence of noise (Firszt et al, 2004; Davidson, 2006;

Davidson et al, 2009; Gifford et al, 2011; Baudhuin et al, 2012; Robinson et al, 2012; Geers et al, 2013; Sheffield et al, 2015; Dwyer et al, 2016; Rakszawski et al, 2016;). Similarly, the PMSTB working group's primary concern centered on defining stimulus parameters that would gauge how well a child was performing for stimulus and noise levels typically encountered, rather than designing a protocol that would simply yield high outcomes. If children with hearing loss exhibit significant difficulty at SNRs most commonly encountered in typical listening environments for preschool- and school-aged children—such as +5 dB SNR—then this provides clinicians with diagnostically relevant information that can guide clinical decision-making. For example, this information could guide clinical recommendations for additional intervention such as initial cochlear implantation, pursuing a second implant, programming different acoustic gain and/or HA characteristics, using CART services in the classroom, full-time use of FM/DM technology, etc.

Normal development of auditory skills depends upon audibility for low-, mid-, and high-level sounds, including speech. The amount of amplification applied to low-level sounds must not interfere with the need to maintain a usable temporal envelope (e.g., preserve speech peaks) and to avoid excessive amplification of noisy signals. Monitoring a child's speech perception requires measures appropriate for a child's chronologic age, cognitive status, language abilities and audibility at multiple intensities (i.e., normal and soft conversational levels) and in multiple listening environments (i.e., in quiet and in competing noise). The PMSTB addresses all points with a standardized protocol appropriate for children with a range of abilities from discrimination in quiet to sentence recognition in noise, and in a variety of settings, from clinic to research.

Limitations

Though the PMSTB offers great benefits to professional and patients, as a working group, we would like to acknowledge that this first iteration has its limitations. First, a limited amount of normative data exists for the current PMSTB measures. This restricts our ability to benchmark a child's static performance and progress over time against typically developing, hearing peers. Second, some of the validated measures selected for the protocol have a limited number of equivalent lists. For some of the PMSTB measures, this constraint prohibits independent assessment of all listening conditions (e.g., left ear, right ear, and bilateral) within a single session. Newer measures have emerged since the initial development of this recommended test battery and could, at some point, become part of the recommended protocol. We have always anticipated that the PMSTB would evolve over time with increased knowledge about development and skills in this population.

As mentioned previously, one of the primary goals for creating a standardized protocol is that, over time, it may afford the development of age-normative data and test–retest variability estimates. This will, in turn, allow reliable benchmarking of patient performance and determination of clinically significant changes based on binomial distribution statistics. Furthermore, we both anticipate and encourage test development including an adequately large number of lists for the accurate and independent evaluation of speech and word recognition in various listening configuration as well as longitudinal assessment.

SUMMARY AND CONCLUSIONS

Measurement of patient outcomes and documentation of treatment efficacy represents an essential component of (re)habilitative audiology. While one could argue that outcome measures themselves do not improve patient outcomes, the adoption and adherence to a standardized assessment protocol can facilitate continuity of care, assist in clinical decision-making, and allow benchmarking against both hearing peers as well as our aggregate clinical population. Additionally, a uniform test battery could aid patient and family counseling regarding expectations and predictions for improvement over time. We expect that the PSMTB will transform over time and as new tests, upgraded technologies, and knowledge about this young population from larger patient populations become available. In the meantime, however, professionals serving families with children with hearing loss cannot allow current limitations impede the development and implementation of standardized assessment battery.

Although the working group wholeheartedly supports establishment of a standardized assessment protocol, we want to emphasize that the PMSTB represents a "minimum" test battery for use with all children at every visit. Individual clinics and clinicians can administer additional assessments at their discretion based on professional judgment and the child's needs.

Review of the current literature highlights a lack of consistency in accepted assessment protocols across laboratories, clinics, and even among clinicians within the same clinic (e.g., Uhler and Gifford, 2014). Given the changing nature of our national healthcare system and federal initiatives designed at improving the quality and efficiency of healthcare and service delivery—including a pay-for-performance model of reimbursement—we can expect that the adoption and implementation of a standardized assessment battery for children with hearing loss will, at a minimum, become the norm. Thus, this PMSTB working group of clinicians, scientists, and industry representatives has developed the first iteration of the PMSTB, which is included in Supplemental Appendix S1. Implementation of the PMSTB in our clinical practice and dissemination of associated data are both critical for achieving the next level of success for our patients and for elevating pediatric audiology, (re)habilitative audiology, as well as pediatric CI and HA research.

REFERENCES

Agency for Healthcare Research and Quality (AHRQ). (2011) Technology assessment: effectiveness of cochlear implants in adults with sensorineural hearing loss. Contract no. 290 2007 10055 1). https://www.cms.gov/Medicare/Coverage/DeterminationProcess/downloads/id80TA.pdf. Accessed August 1, 2016

Agency for Healthcare Research and Quality (AHRQ). (2014) Methods guide for comparative effectiveness comparative reviews. Publication no. 10(14)-EHC063-EF. https://effectivehealthcare.ahrq.gov/ehc/products/60/318/CER-Methods-Guide-140109.pdf. Accessed August 1, 2016

Akhtar N, Jipson J, Callanan MA. (2001) Learning words through overhearing. *Child Dev* 72(2):416–430.

Ambrose SE, Berry LMU, Walker EA, Harrison M, Oleson J, Moeller MP. (2014) Speech sound production in 2-year-olds who are hard of hearing. *Am J Speech Lang Pathol* 23:91–104.

Baudhuin J, Cadieux J, Firszt JB, Reeder RM, Maxson JL. (2012) Optimization of programming parameters in children with the advanced bionics cochlear implant. *J Am Acad Audiol* 23(5):302–312.

Bench J, Kowal A, Bamford J. (1979) The BKB (Bamford-Kowal-Bench) sentence lists for partially-hearing children. *Br J Audiol* 13(3):108–112.

Bess FH, Sinclair JS, Riggs DE. (1984) Group amplification in schools for the hearing impaired. *Ear Hear* 5(3):138–144.

Beyea JA, McMullen KP, Harris MS, Houston DM, Martin JM, Bolster VA, Adunka OF, Moberly AC. (2016) Cochlear implants in adults: effects of age and duration of deafness on speech recognition. *Otol Neurotol* 37(9):1238–1245.

Boothroyd A. (1995) Speech perception tests and hearing impaired children. In: Plant G, Spens KE, eds. *Profound Deafness and Speech Communication*. London, UK: Whurr.

Boothroyd A, Geers AE, Moog JS. (1991) Practical implications of cochlear implants in children. *Ear Hear* 12(4, Suppl):81S–89S.

Brand Y, Senn P, Kompis M, Dillier N, Allum JH. (2014) Cochlear implantation in children and adults in Switzerland. *Swiss Med Wkly* 144:w13909.

Centers for Medicare and Medicaid Services. (2004) The CMS approved coverage with evidence development (CED) study protocol CAG-00107N, CMS. https://www.cms.gov/medicare-coverage-database/details/nca-decision-memo.aspx?NCAId=134&NcaName=Cochlear+Implantation&NCDId=245&ncdver=2&IsPopup=y&bc=AAAAAAAAIAAA&. December 21, 2016.

Ching TYC, Leigh G, Dillon H. (2013) Introduction to the longitudinal outcomes of children with hearing impairment (LOCHI) study: background, design, sample characteristics. *Int J Audiol* 52(2, Suppl):S4–S9.

Clark W, Govett S. (1995) School-related noise exposure in children. Paper presented at the Association for Research in in Otolaryngology Mid-Winter Meeting. St. Petersburg, FL.

Coninx F, Weichbold V, Tsiakpini L, et al. (2009) Validation of the LittlEARS((R)) Auditory Questionnaire in children with normal hearing. *Int J Pediatr Otorhinolaryngol* 73(12):1761–1768.

Crandell C, Smaldino J. (1995) An update of classroom acoustics for children with hearing impairment. *Volta Review* 1:4–12.

Crukley J, Scollie S, Parsa V. (2011) An exploration of non-quiet listening at school. *J Ed Audiol* 17:23–35.

Davidson LS. (2006) Effects of stimulus level on the speech perception abilities of children using cochlear implants or digital hearing aids. *Am J Audiol* 15(2):141–153.

Davidson LS, Skinner MW, Holstad BA, Fears BT, Richter MK, Matusofsky M, Brenner C, Holden T, Birath A, Kettel JL, Scollie S. (2009) The effect of instantaneous input dynamic range setting on the speech perception of children with the nucleus 24 implant. *Ear Hear* 30(3):340–349.

Desai S, Stickney G, Zeng FG. (2008) Auditory-visual speech perception in normal-hearing and cochlear-implant listeners. *J Acoust Soc Am* 123(1):428–440.

Dorman MF, Cook S, Spahr A, Zhang T, Loiselle L, Schramm D, Whittingham J, Gifford R. (2015) Factors constraining the benefit to speech understanding of combining information from low-frequency hearing and a cochlear implant. *Hear Res* 322:107–111.

Dorman M, Spahr A, Gifford RH, Cook S, Zhang T, Loiselle L, Whittingham J, Schramm D. (2012) Bilateral and bimodal benefit as a function of age for adults. *J Hear Sci* 2(4):37–39.

Dwyer RT, Spahr T, Agrawal S, Hetlinger C, Holder JT, Gifford RH. (2016) Participant-generated cochlear implant programs: speech recognition, sound quality, and satisfaction. *Otol Neurotol* 37(7):e209–e216.

Eilers RE, Wilson WR, Moore JM. (1977) Developmental changes in speech discrimination in infants. *J Acoust Soc Am* 20:766–780.

Eisenberg LS, Johnson KC, Martinez AS, Cokely CG, Tobey EA, Quittner AL, Fink NE, Wang NY, Niparko JK; CDaCI Investigative Team (2006). Speech recognition at 1-year follow-up in the childhood development after cochlear implantation study: methods and preliminary findings. *Audiol Neurootol* 11(4):259–268.

Eisenberg LS, Martinez AS, Boothroyd A. (2003) Auditory-visual and auditory-only perception of phonetic contrasts in children. *Volta Review* 103:327–346.

Eisenberg LS, Boothroyd A, Martinez AS. (2004) Cochlear Implants International Congress Series. The perception of phonetic contrasts in infants: development of the VRASPAC. Vol. 1273, pp. 364–367. Amsterdam, The Netherlands: Elsevier.

Eshraghi AA, Nazarian R, Telischi FF, Martinez D, Hodges A, Velandia S, Cejas-Cruz I, Balkany TJ, Lo K, Lang D. (2015) Cochlear implantation in children with autism spectrum disorder. *Otol Neurotol* 36(8):e121–e128.

Etymōtic Research, Inc. (2005) BKB-SIN test. Speech-in-Noise Test Version 1.03, 2005. 61 Martin Lane, Elk Grove Village, IL. www.etymotic.com/auditory-research/speech-in-noise-tests/bkb-sin.html. Accessed December 21, 2016.

Eze N, Ofo E, Jiang D, O'Connor AF. (2013) Systematic review of cochlear implantation in children with developmental disability. *Otol Neurotol* 34(8):1385–1393.

Fenson L, Marchman VA, Thal DJ, Dale PS, Reznick JS, Bates E. (2007) *MacArthur-Bates Communicative Development*

Inventories: User's Guide and Technical Manual. 2nd ed. Baltimore, MD: Brookes Publishing.

Finitzo-Hieber T (1988). Classroom acoustics. In: Roeser R, ed. *Auditory Disorders in School Children*. 2nd ed. New York, NY: Thieme-Stratton, 221–223.

Fink NE, Wang NY, Visaya J, Niparko JK, Quittner A, Eisenberg LS, Tobey EA; CDACI Investigative Team (2007). Childhood Development after Cochlear Implantation (CDaCI) study: design and baseline characteristics. *Cochlear Implants Int* 8(2):92–116.

Firszt JB, Holden LK, Skinner MW, Tobey EA, Peterson A, Gaggl W, Runge-Samuelson CL, Wackym PA. (2004) Recognition of speech presented at soft to loud levels by adult cochlear implant recipients of three cochlear implant systems. *Ear Hear* 25(4):375–387.

Fulcher A, Purcell AA, Baker E, Munro N. (2012) Listen up: children with early identified hearing loss achieve age-appropriate speech/language outcomes by 3 years-of-age. *Int J Pediatr Otorhinolaryngol* 76(12):1785–1794.

Ganger J, Brent MR. (2004) Reexamining the vocabulary spurt. *Dev Psychol* 40(4):621–632.

Geers AE, Davidson LS, Uchanski RM, Nicholas JG. (2013) Interdependence of linguistic and indexical speech perception skills in school-age children with early cochlear implantation. *Ear Hear* 34(5):562–574.

Gifford RH, Dorman MF, Sheffield SW, Teece K, Olund AP. (2014) Availability of binaural cues for bilateral implant recipients and bimodal listeners with and without preserved hearing in the implanted ear. *Audiol Neurootol* 19(1):57–71.

Gifford RH, Olund AP, Dejong M. (2011) Improving speech perception in noise for children with cochlear implants. *J Am Acad Audiol* 22(9):623–632.

Gifford RH, Shallop JK, Peterson AM. (2008) Speech recognition materials and ceiling effects: considerations for cochlear implant programs. *Audiol Neurootol* 13(3):193–205.

Govaerts PJ, Daemers K, Yperman M, De Beukelaer C, De Saegher G, De Ceulaer G. (2006) Auditory speech sounds evaluation (A(section)E): a new test to assess detection, discrimination and identification in hearing impairment. *Cochlear Implants Int* 7(2):92–106.

Govaerts PJ, Vaerenberg B, De Ceulaer G, Daemers K, De Beukelaer C, Schauwers K. (2010) Development of a software tool using deterministic logic for the optimization of cochlear implant processor programming. *Otol Neurotol* 31(6):908–918.

Harris PA, Taylor R, Thielke R, Payne J, Gonzalez N, Conde JG. (2009) Research electronic data capture (REDCap)—a metadata-driven methodology and workflow process for providing translational research informatics support. *J Biomed Inform* 42(2):377–381.

Hart TR, Risley B. (1995) *Meaningful Differences in the Everyday Experience of Young American Children*. Baltimore, MD: Paul H. Brookes Publishing.

Hayes H, Geers AE, Treiman R, Moog JS. (2009) Receptive vocabulary development in deaf children with cochlear implants: achievement in an intensive auditory-oral educational setting. *Ear Hear* 30(1):128–135.

Hillock-Dunn A, Buss E, Duncan N, Roush PA, Leibold LJ. (2014) Effects of nonlinear frequency compression on speech identification in children with hearing loss. *Ear Hear* 35(3):353–365.

Hillock-Dunn A, Taylor C, Buss E, Leibold LJ. (2015) Assessing speech perception in children with hearing loss: what conventional clinical tools may miss. *Ear Hear* 36(2):e57–e60.

Holte L, Walker E, Oleson J, Spratford M, Moeller MP, Roush P, Ou H, Tomblin JB. (2012) Factors influencing follow-up to newborn hearing screening for infants who are hard of hearing. *Am J Audiol* 21(2):163–174.

Huttenlocher J, Vasilyeva M, Cymerman E, Levine S. (2002) Language input and child syntax. *Cognit Psychol* 45(3):337–374.

Inscoe JR, Bones C. (2016) Additional difficulties associated with aetiologies of deafness: outcomes from a parent questionnaire of 540 children using cochlear implants. *Cochlear Implants Int* 17(1):21–30.

Jerger S, Jerger J, Abrams S. (1983) Speech audiometry in the young child. *Ear Hear* 4(1):56–66.

Kashinath S, Woods J, Goldstein H. (2006) Enhancing generalized teaching strategy use in daily routines by parents of children with autism. *J Speech Lang Hear Res* 49(3):466–485.

Kent RD, Osberger MJ, Netsell R, Hustedde CG. (1987) Phonetic development in identical twins differing in auditory function. *J Speech Hear Disord* 52(1):64–75.

Kirk KI, French B, Choi S. (2009) Assessing spoken word recognition in children with cochlear implants. In: Eisenberg LS, ed. *Clinical Management of Children with Cochlear Implants*. San Diego, CA: Plural Publishers.

Kirk KI, Pisoni DB, Osberger MJ. (1995) Lexical effects on spoken word recognition by pediatric cochlear implant users. *Ear Hear* 16(5):470–481.

Kirk KI, Pisoni DB, Sommers MS, Young M, Evanson C. (1995) New directions for assessing speech perception in persons with sensory aids. *Ann Otol Rhinol Laryngol Suppl* 166:300–303.

Koch DB, Quick A, Osberger MJ, Saoji A, Litvak L. (2014) Enhanced hearing in noise for cochlear implant recipients: clinical trial results for a commercially available speech-enhancement strategy. *Otol Neurotol* 35(5):803–809.

Koehlinger KM, Van Horne AJO, Moeller MP. (2013) Grammatical outcomes of 3- and 6-year-old children who are hard of hearing. *J Speech Lang Hear Res* 56(5):1701–1714.

Kuehn-Inacken H, Weichboldt V, Tsiakpini L, Coninx F, D'Haese P. (2003) LittlEARS Auditory questionnaire: parents questionnaire to assess auditory behaviour. Innsbruck, Austria: MedEl.

Landry SH, Smith KE, Swank PR, Miller-Loncar CL. (2000) Early maternal and child influences on children's later independent cognitive and social functioning. *Child Dev* 71(2):358–375.

Law J, Rush R, Schoon I, Parsons S. (2009) Modeling developmental language difficulties from school entry into adulthood: literacy, mental health, and employment outcomes. *J Speech Lang Hear Res* 52(6):1401–1416.

Leibold LJ, Hillock-Dunn A, Duncan N, Roush PA, Buss E. (2013) Influence of hearing loss on children's identification of spondee words in a speech-shaped noise or a two-talker masker. *Ear Hear* 34(5):575–584.

Olsen WO. (1998) Average speech levels and spectra in various speaking/listening conditions: a summary of the Pearson, Bennett, and Fidell (1977) report. *Am J Audiol* 7(2):21–25.

Mahmoud AF, Ruckenstein MJ. (2014) Speech perception performance as a function of age at implantation among postlingually deaf adult cochlear implant recipients. *Otol Neurotol* 35(10):e286–e291.

Martinez A, Eisenberg L, Boothroyd A, Visser-Dumont L. (2008) Assessing speech pattern contrast perception in infants: Early results on VRASPAC. *Otol Neuroto* 29:183–188.

Massa ST, Ruckenstein MJ. (2014) Comparing the performance plateau in adult cochlear implant patients using HINT and AzBio. *Otol Neurotol* 35(4):598–604.

Mayne A, Yoshinaga-Itano C, Sedey AL. (2000) Receptive vocabulary development of infants and toddlers who are deaf or hard of hearing. *Volta Review* 100:29–52.

Mayne AM, Yoshinaga-Itano C, Sedey AL, Carey A. (2000) Expressive vocabulary development of infants and toddlers who are deaf or hard of hearing. *Volta Review* 100:1–28.

McCreery RW, Alexander J, Brennan MA, Hoover B, Kopun J, Stelmachowicz PG. (2014) The influence of audibility on speech recognition with nonlinear frequency compression for children and adults with hearing loss. *Ear Hear* 35(4):440–447.

McCreery RW, Walker EA, Spratford M, Oleson J, Bentler R, Holte L, Roush P. (2015) Speech recognition and parent ratings From auditory development questionnaires in children who are hard of hearing. *Ear Hear* 36(1, Suppl):60S–75S.

McGuckian M, Henry A. (2007) The grammatical morpheme deficit in moderate hearing impairment. *Int J Lang Commun Disord* 42(1, Suppl):17–36.

McMurray B. (2007) Defusing the childhood vocabulary explosion. *Science* 317(5838):631.

Meinzen-Derr J, Wiley S, Creighton J, Choo D. (2007) Auditory Skills Checklist: clinical tool for monitoring functional auditory skill development in young children with cochlear implants. *Ann Otol Rhinol Laryngol* 116(11):812–818.

Minimum-Speech-Test-Battery (MSTB). (2011) The new minimum speech test battery. http://www.auditorypotential.com/MSTB_Nav.html. Accessed December 21, 2016.

Moeller MP, Hoover B, Putman C, Arbataitis K, Bohnenkamp G, Peterson B, Lewis D, Estee S, Pittman A, Stelmachowicz P. (2007) Vocalizations of infants with hearing loss compared with infants with normal hearing: part I—phonetic development. *Ear Hear* 28(5):605–627.

Moeller MP, Hoover B, Putman C, Arbataitis K, Bohnenkamp G, Peterson B, Wood S, Lewis D, Pittman A, Stelmachowicz P. (2007) Vocalizations of infants with hearing loss compared with infants with normal hearing: part II—transition to words. *Ear Hear* 28(5): 628–642.

Moog J, Geers A. (1990) *Early Speech Perception Test*. St. Louis, MO: Central Institute for the Deaf.

Moore J, Thompson G, Thompson M. (1975) Auditory localization of infants as a function of reinforcement conditions. *J Speech Lang Hear Dis* 40:29–34.

Niparko JK, Tobey EA, Thal DJ, Eisenberg LS, Wang NY, Quittner AL, Fink NE; CDaCI Investigative Team (2010). Spoken language development in children following cochlear implantation. *JAMA* 303(15):498–506.

Nober L, Nober E. (1975) Auditory discrimination of learning disabled children in quiet and classroom noise. *J Learn Disabil* 8:656–659.

Nozza RJ. (1987) Infant speech-sound discrimination testing: Effects of stimulus intensity and procedural model on measures of performance. *J Acoust Soc Am* 81:1928–1939.

Olds C, Pollonini L, Abaya H, Larky J, Loy M, Bortfeld H, Beauchamp MS, Oghalai JS. (2016) Cortical activation patterns correlate with speech understanding after cochlear implantation. *Ear Hear* 37(3):e160–e172.

Oller DK, Eilers RE. (1988) The role of audition in infant babbling. *Child Dev* 59(2):441–449.

Osberger MJ, Miyamoto RT, Zimmerman-Phillips S, Kemink JL, Stroer BS, Firszt JB, Novak MA. (1991) Independent evaluation of the speech perception abilities of children with the Nucleus 22-channel cochlear implant system. *Ear Hear* 12(4, Suppl): 66S–80S.

Pearsons K, Bennett R, Fidell S. (1977) *Speech Levels in Various Environments*. Washington, DC: Office of Health and Ecological Effects, Office of Research and Development, US EPA.

Pediatric Minimum Speech Test Battery Working Group (PMSTB). (2013) Meeting minutes, project updates and file cabinets. https://sites.google.com/site/pediatricmstbworkinggroup/home. Accessed December 21, 2016.

Peterson GE, Lehiste I. (1962) Revised CNC lists for auditory tests. *J Speech Hear Disord* 27:62–70.

Rakszawski B, Wright R, Cadieux JH, Davidson LS, Brenner C. (2016) The effects of preprocessing strategies for pediatric cochlear implant recipients. *J Am Acad Audiol* 27(2):85–102.

Robbins AM, Kirk KI. (1996) Speech perception assessment and performance in pediatric cochlear implant users. *Semin Hear* 17:353–369.

Robinson EJ, Davidson LS, Uchanski RM, Brenner CM, Geers AE. (2012) A longitudinal study of speech perception skills and device characteristics of adolescent cochlear implant users. *J Am Acad Audiol* 23(5):341–349.

Roeser R, Clark J. (2008) Live voice speech recognition audiometry: stop the madness. *Audiol Today* 20:32–33.

Roland JT, Jr, Gantz BJ, Waltzman SB, Parkinson AJ; Multicenter Clinical Trial Group (2016). United States multicenter clinical trial of the cochlear nucleus hybrid implant system. *Laryngoscope* 126(1):175–181.

Runge CL, Henion K, Tarima S, Beiter A, Zwolan TA. (2016) Clinical outcomes of the Cochlear™ Nucleus(®) 5 Cochlear Implant System and SmartSound™ 2 Signal Processing. *J Am Acad Audiol* 27(6):425–440.

Sanders DA. (1965) Noise conditions in normal school classrooms. *Except Child* 31:344–353.

Sarant JZ, Holt CM, Dowell RC, Rickards FW, Blamey PJ. (2009) Spoken language development in oral preschool children with permanent childhood deafness. *J Deaf Stud Deaf Educ* 14(2):205–217.

Schafer EC. (2010) Speech perception in noise measures for children: a critical review and case studies. *J. Ed Audiol* 16:4–15.

Sheffield SW, Haynes DS, Wanna GB, Labadie RF, Gifford RH. (2015) Availability of binaural cues for pediatric bilateral cochlear implant recipients. *J Am Acad Audiol* 26(3):289–298.

Skinner MW, Holden LK, Holden TA, Demorest ME. (1999) Comparison of two methods for selecting minimum stimulation levels used in programming the Nucleus 22 cochlear implant. *J Speech Lang Hear Res* 42(4):814–828.

Smeds K, Wolters F, Rung M. (2015) Estimation of signal-to-noise ratio in realistic sound scenarios. *J Am Acad Audiol* 26(2):183–196.

Spahr AJ, Dorman MF, Litvak LM, Cook SJ, Loiselle LM, DeJong MD, Hedley-Williams A, Sunderhaus LS, Hayes CA, Gifford RH. (2014) Development and validation of the pediatric AzBio sentence lists. *Ear Hear* 35(4):418–422.

Spahr AJ, Dorman MF, Loiselle LH. (2007) Performance of patients using different cochlear implant systems: effects of input dynamic range. *Ear Hear* 28(2):260–275.

Stelmachowicz P, Lewis D, Hoover B, Nishi K, McCreery R, Woods W. (2010) Effects of digital noise reduction on speech perception for children with hearing loss. *Ear Hear* 31(3):345–355.

Stelmachowicz PG, Pittman AL, Hoover BM, Lewis DE. (2002) Aided perception of /s/ and /z/ by hearing-impaired children. *Ear Hear* 23(4):316–324.

Stoel-Gammon C, Otomo K. (1986) Babbling development of hearing-impaired and normally hearing subjects. *J Speech Hear Disord* 51(1):33–41.

Suskind D, Leffel KR, Hernandez MW, Sapolich SG, Suskind E, Kirkham E, Meehan P. (2013) An exploratory study of "quantitative linguistic feedback": effect of LENA feedback on adult language production. *Comm Disord Q* 34(4):199–209.

Tobey EA, Geers AE, Brenner C, Altuna D, Gabbert G. (2003) Factors associated with development of speech production skills in children implanted by age five. *Ear Hear* 24(1, Suppl):36S–45S.

Tobey EA, Geers AE, Sundarrajan M, Shin S. (2011) Factors influencing speech production in elementary and high school-aged cochlear implant users. *Ear Hear* 32(1, Suppl):27S–38S.

Tobey EA, Thal D, Niparko JK, Eisenberg LS, Quittner AL, Wang NY; CDaCI Investigative Team (2013). Influence of implantation age on school-age language performance in pediatric cochlear implant users. *Int J Audiol* 52(4):219–229.

Tomblin JB, Oleson JJ, Ambrose SE, Walker E, Moeller MP. (2014) The influence of hearing aids on the speech and language development of children with hearing loss. *JAMA Otolaryngol Head Neck Surg* 140(5):403–409.

Tomblin JB, Spencer L, Flock S, Tyler R, Gantz B. (1999) A comparison of language achievement in children with cochlear implants and children using hearing aids. *J Speech Lang Hear Res* 42(2):497–509.

Tomblin JB, Walker EA, McCreery RW, Arenas RM, Harrison M, Moeller MP. (2015) Outcomes of children with hearing loss: data collection and methods. *Ear Hear* 36(1, Suppl 1):14S–23S.

Tyler RS, Berliner KI, Demorest ME, Hirshorn MS, Luxford WM, Mangham CA. (1986) Clinical objectives and research design issues for cochlear implants in children. *Semin Hear* 7:433–440.

Tyler RS, Davis JM, Lansing CR. (1987) Cochlear implants in young children. *ASHA* 29(4):41–49.

Uhler K. (2014) Relationship between speech perception and language. Ultimate Colorado Midwinter Meeting, Vail, CO, February 2014.

Uhler KM, Baca R, Dudas E, Fredrickson T. (2015) Refining stimulus parameters in assessing infant speech perception using visual reinforcement infant speech discrimination: sensation level. *J Am Acad Audiol* 26(10):807–814.

Uhler K, Biever A, Gifford RH. (2016) Method of speech stimulus presentation impacts pediatric speech recognition: monitored live voice versus recorded speech. *Otol Neurotol* 37(2):e70–e74.

Uhler K, Burns S, Dalpes M, Yoshinaga-Itano C (2011) An auditory spoken language matrix for differential diagnosis of Spanish-speaking children who are deaf or hard of hearing. *ASHA Spec Interes Group* 1418:71–78. doi:10.1044/cds18.3.71

Uhler K, Gifford RH. (2014) Current trends in pediatric cochlear implant candidate selection and postoperative follow-up. *Am J Audiol* 23(3):309–325.

Waltzman S, Cohen NL, Spivak L, Ying E, Brackett D, Shapiro W, Hoffman R. (1990) Improvement in speech perception and production abilities in children using a multichannel cochlear implant. *Laryngoscope* 100(3):240–243.

Wang NY, Eisenberg LS, Johnson KC, Fink NE, Tobey EA, Quittner AL, Niparko JK; CDaCI Investigative Team (2008). Tracking development of speech recognition: longitudinal data from hierarchical assessments in the Childhood Development after Cochlear Implantation Study. *Otol Neurotol* 29(2): 240–245.

Warner-Czyz AD, Davis BL. (2008) The emergence of segmental accuracy in young cochlear implant recipients. *Cochlear Implants Int* 9(3):143–166.

Warner-Czyz AD, Davis BL, MacNeilage PF. (2010) Accuracy of consonant-vowel syllables in young cochlear implant recipients and hearing children in the single-word period. *J Speech Lang Hear Res* 53(1):2–17.

Wolfe J, Neumann S, Marsh M, Schafer E, Lianos L, Gilden J, O'Neill L, Arkis P, Menapace C, Nel E, Jones M. (2015) Benefits of adaptive signal processing in a commercially available cochlear implant sound processor. *Otol Neurotol* 36(7): 1181–1190.

Yoshinaga-Itano C, Baca RL, Sedey AL. (2010) Describing the trajectory of language development in the presence of severe-to-profound hearing loss: a closer look at children with cochlear implants versus hearing aids. *Otol Neurotol* 31(8): 1268–1274.

Yoshinaga-Itano C, Sedey AL, Coulter DK, Mehl AL. (1998) Language of early- and later-identified children with hearing loss. *Pediatrics* 102(5):1161–1171.

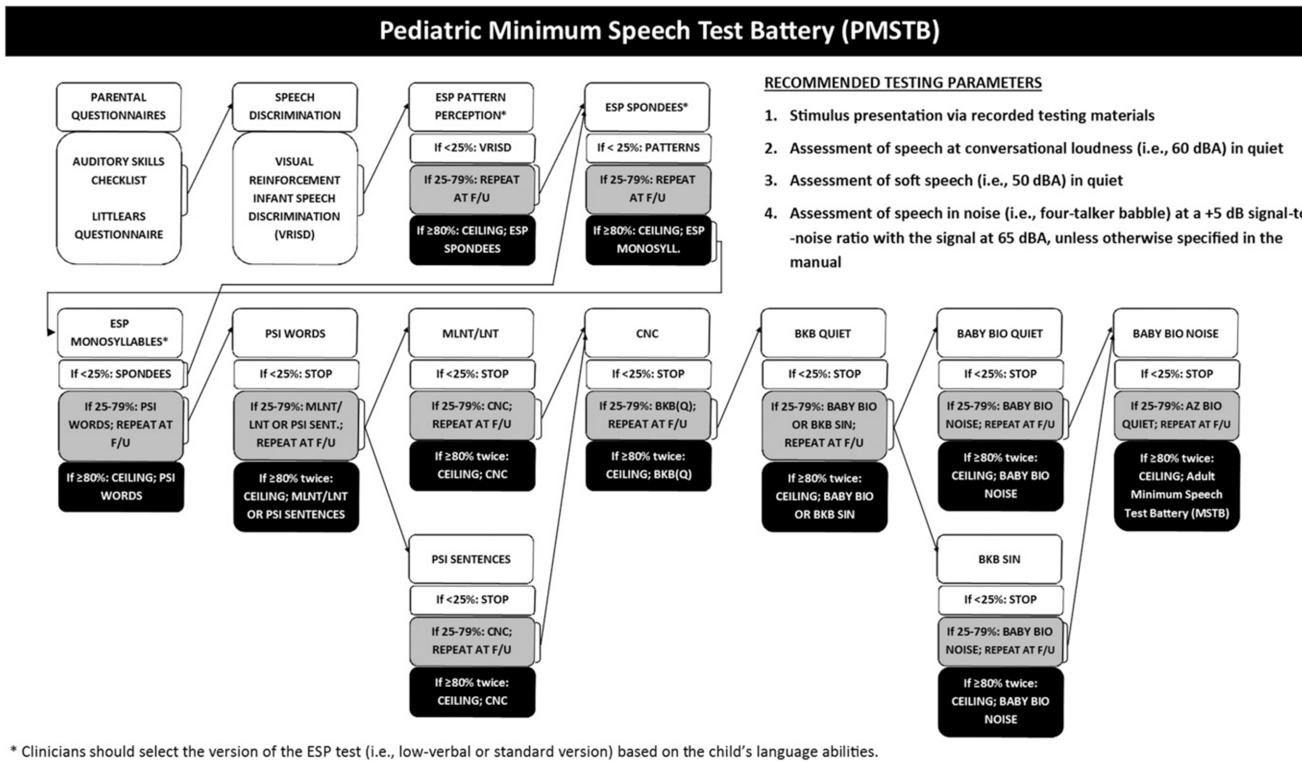
Yoshinaga-Itano C, Sedey A. (2000) Early speech development in children who are deaf or hard of hearing: interrelationships with language and hearing. *Volta Review* 100:181–211.

PMSTB Working Group. The Pediatric Minimum Speech Test Battery (PMSTB) working group consisted of 56 clinicians and researchers from across the United States. Kristin Uhler served as the chair of the working group. René Gifford and Andrea Warner-Czyz acted as co-chairs of the working group.

Full authorship list: Kristin Uhler, PhD, University of Colorado Denver School of Medicine, Aurora, CO; René H. Gifford, PhD, Vanderbilt University, Nashville, TN; Andrea Warner-Czyz, PhD, The University of Texas at Dallas, Dallas, TX; Mary Archer, AuD, West Virginia University HealthCare Children's Hospital; Katie Austin, AuD, Kentucky Hearing Clinic, Louisville, KY; Mary M. "Peg" Barry, AuD, Commission for Children with Special Health Care Needs, Louisville, KY; Allison Biever, AuD, Rocky Mountain ENT, Englewood, CO; Michelle Blanchard, AuD, Tampa Bay Hearing and Balance, Tampa, FL; Rebecca Brashears, University of South Carolina, Columbia, SC; Claire Buxton, AuD, University of Maryland, College Park, MD; Tina Childress, AuD, CASE Audiology, Champaign, IL; Rachel Cooper, AuD,

University of Mississippi Medical Center, Jackson, MS; Beth Czarnecki, AuD, Penn State Hershey, Hershey, PA; Laurie Eisenberg, PhD, University of Southern California, Los Angeles, CA; Shannon Elam, AuD, University of Colorado Hearing and Balance Center, Aurora, CO; Melissa Ferrello, AuD, Children's Hospital of Philadelphia, Philadelphia, PA; Lia Ferro, AuD, University of Chicago, Chicago, IL; Hillary Gazeley, AuD, Medical College of Wisconsin, Milwaukee, WI; Ann Geers, PhD, The University of Texas at Dallas, Dallas, TX; Katelyn Glassman, AuD, MED-EL Corporation, Raleigh Durham, NC; Janet Green, AuD, NYU Langone Medical Center, New York, NY; Aimee Gross, MS, MED-EL Corporation, Raleigh Durham, NC; Carmen Hayman, AuD, Children's Hospital of Philadelphia, Philadelphia, PA; Nikki Herrod-Burrows, AuD, University of South Carolina, Columbia, SC; Kathi Henion, AuD, Advanced Bionics, Sylmar, CA; Michelle Hughes, PhD, Boys Town National Research Hospital, Omaha, NE; Yell Inverso, AuD, PhD, Nemours/Alfred I. duPont Hospital for Children, Wilmington, DE; Karen Johnson, PhD, Keck School of Medicine USC, Los Angeles, CA; Karen Kirk, PhD, The University of Illinois at Urbana-Champaign, Urbana-Champaign, IL; Kirsten Kramer, AuD, Helen DeVos Children's Hospital, Grand Rapids, MI; Leslie Lianos, MS, Dallas Ear Institute, Dallas, TX; Liesl Looney, AuD, Nemours/Alfred I. duPont Hospital for Children, Wilmington, DE; Jane Madell, PhD, Pediatric Audiology Consulting, Brooklyn, NY; Deanna Matusik, AuD, University of Illinois Medical Center, Chicago, IL; Shelley Moats, AuD, Little Ears Hearing Center, Louisville, KY; Lori O'Neill, AuD, Cochlear Americas, Centennial, CO; Kathryn Pegan, AuD, Clinical Trainer at Phonak, LLC, Warrenville, IL; Pritesh Pandya, PhD, MED-EL Corporation, Raleigh Durham, NC; Sarah F. Poissant, PhD, University of Massachusetts, Amherst, MA; Wendy Potts, AuD, Cochlear Corporation, Denver, CO; Allison Ramakrishnan, AuD, University of Colorado Hearing and Balance Center, Aurora, CO; Jennifer Raulie, MA, Advanced Bionics, Sylmar, CA; Riza Razack, AuD, Director of Riza Razack Consulting, North York, ON, Canada; Michael Scott, AuD, Cincinnati Children's, Cincinnati, OH; Jared Shifflet, M.A. Advanced Bionics, Sylmar, CA; Carrie Spangler, AuD, Summit County Educational Service Center, Cleveland, OH; Melissa Sweeney, MS, The University of Texas at Dallas, Dallas, TX; Sarah Sydlowski, AuD, PhD, Cleveland Clinic, Cleveland, OH; Holly Teagle, AuD, University of North Carolina School of Medicine, Chapel Hill, NC; Denise Thomas, AuD, Ann and Robert H. Lurie Children's Hospital of Chicago, Chicago, IL; Nanette Thompson, MS, Listen Foundation, Englewood, CO; Julie Verhoff, AuD, The River School, Washington, DC; Dawn Violetto, AuD, Child's Voice, Wood Dale, IL; Rachel Vovos, AuD, Advanced Bionics, Sylmar, CA; Cynthia Warner, AuD, Nationwide Children's Hospital, Columbus, OH; Julia Webb, AuD, Arkansas Children's Hospital, Little Rock, AR; Louisa Yong Yan Ha, AuD, Thomas Jefferson University Hospitals, Philadelphia, PA; Christie Yoshinaga-Itano, PhD, University of Colorado, Boulder, CO; Terry Zwolan, PhD, University of Michigan, Ann Arbor, MI.

APPENDIX A



APPENDIX B

Details for Ordering Specific Test Measures

Test	Authors (Year)	Ordering/Download Information
Auditory Skills Checklist (ASC)	Meinzen-Derr et al (2004)	*Annals of Otology, Rhinology, and Laryngology*, 116 (11):812–818.
Bamford–KowalBench (BKB) Sentences in Quiet and in Noise (BKB-SIN)	Bench et al (1979); Etymotic Research (2005)	Auditec (www.auditec.com) Etymotic Research (www.etymotic.com)
Consonant-Nucleus-Consonant (CNC)	Peterson and Lehiste (1962)	Bio-logic Systems Corp. (http://www.bionicear.com/For_Professionals/Audiology_Support/CNC_Test.cfm?)
Early Speech Perception Test	Moog and Geers (1990)	Central Institute for the Deaf (http://www.cid.edu/ProfOutreachIntro/EducationalMaterials.aspx)
Lexical Neighborhood Test (LNT)	Kirk et al (1995)	Auditec (www.auditec.com)
LittlEars Auditory Questionnaire	Kuhn-Inacker et al (2003)	Med El (http://s3.medel.com/downloadmanager/downloads/bridge_us/en-US/BRIDGE_Order_Form.pdf)
Multisyllabic Lexical Neighborhood Test (MLNT)	Kirk et al (1995)	Auditec (www.auditec.com)
Pediatric AzBio Sentence Lists	Spahr et al (2014)	Auditory Potential (http://www.auditorypotential.com/purchase.html)
Pediatric Speech Intelligibility (PSI)	Jerger and Jerger (1984)	Auditec (www.auditec.com)

TABLE OF CONTENTS

Authors

Kristin Uhler, PhD* -University of Colorado Denver School of Medicine, Aurora, CO
René H. Gifford, PhD* - Vanderbilt University, Nashville, TN
Andrea Warner-Czyz, PhD* - The University of Texas at Dallas, Dallas, TX
Mary Archer, AuD- West Virginia University HealthCare Children's Hospital
Katie Austin, AuD – Kentucky Hearing Clinic, Louisville, KY
Mary M. "Peg" Barry, AuD – Commission for Children with Special Health Care Needs, Louisville, KY
Allison Biever, AuD – Rocky Mountain ENT, Englewood, CO
Michelle Blanchard, AuD – Tampa Bay Hearing and Balance, Tampa, FL
Rebecca Brashears – University of South Carolina, Columbia, SC
Claire Buxton, AuD – University of Maryland, College Park, MD
Tina Childress, AuD – CASE Audiology, Champaign, IL
Rachel Cooper, AuD – University of Mississippi Medical Center, Jackson, MS
Beth Czarnecki, AuD – Penn State Hershey, Hershey, PA
Laurie Eisenberg, PhD – University of Southern California, Los Angeles, California
Shannon Elam, AuD – University of Colorado Hearing and Balance Center, Aurora, CO
Melissa Ferrello, AuD - Children's Hospital of Philadelphia, Philadelphia, PA
Lia Ferro, AuD – University of Chicago, Chicago, IL
Hillary Gazeley, AuD – Medical College of Wisconsin, Milwaukee, WI
Ann Geers, PhD - The University of Texas at Dallas, Dallas, Texas
Katelyn Glassman, AuD-MED-EL Corporation Raleigh Durham, NC
Janet Green, AuD – NYU Langone Medical Center, New York, NY
Aimee Gross, MS- MED-EL Corporation Raleigh Durham, NC
Carmen Hayman, AuD - Children's Hospital of Philadelphia, Philadelphia, PA
Nikki Herrod-Burrows, AuD – University of South Carolina, Columbia, SC
Kathi Henion, AuD-Advanced Bionics, Sylmar, CA
Michelle Hughes, PhD – Boys Town National Research Hospital, Omaha, Nebraska
Yell Inverso, AuD, PhD - Nemours/Alfred I. duPont Hospital for Children, Wilmington, DE
Karen Johnson, PhD – Keck School of Medicine USC, Los Angeles, CA
Karen Kirk, PhD – The University of Illinois at Urbana-Champaign, Urbana-Champaign, IL
Kirsten Kramer, AuD - Helen DeVos Children's Hospital, Grand Rapids, MI
Leslie LIanos, MS – Dallas Ear Institute, Dallas, TX
Liesl Looney, AuD - Nemours/Alfred I. duPont Hospital for Children, Wilmington, DE
Jane Madell, PhD – Pediatric Audiology Consulting, Brooklyn, NY
Deanna Matusik, AuD – University of Illinois Medical Center, Chicago, IL
Shelley Moats, AuD - Little Ears Hearing Center, Louisville, KY
Lori O'Neill, AuD – Cochlear Americas, Centennial, CO
Kathryn Pegan, AuD - Clinical Trainer at Phonak, LLC, Warrenville, IL
Pritesh Pandya, PhD-MED-EL Corporation Raleigh Durham, NC
Sarah F. Poissant, PhD – University of Massachusetts, Amherst, MA
Wendy Potts, AuD – Cochlear Corporation, Denver, CO
Allison Ramakrishnan, AuD – University of Colorado Hearing and Balance Center, Aurora, CO

Jennifer Raulie, MA,- Advanced Bionics, Sylmar, CA
Riza Razack, AuD - Director of Riza Razack Consulting, North York, Ontario, Canada
Michael Scott, AuD - Cincinnati Children's, Cincinnati, Ohio
Jared Shifflet, M.A. Advanced Bionics, Sylmar, CA
Carrie Spangler, AuD - Summit County Educational Service Center, Cleveland, OH
Melissa Sweeney, MS – The University of Texas at Dallas, Dallas, Texas
Sarah Sydlowski, AuD, PhD, Cleveland Clinic, Cleveland, Ohio
Holly Teagle, AuD – University of North Carolina School of Medicine, Chapel Hill, North Carolina
Denise Thomas, AuD - Ann and Robert H. Lurie Children's Hospital of Chicago, Chicago, IL
Nanette Thompson, MS – Listen Foundation, Englewood, Colorado
Julie Verhoff, AuD – The River School, Washington, DC
Dawn Violetto, AuD – Child's Voice, Wood Dale, Illinois
Rachel Vovos, AuD- Advanced Bionics, Sylmar, CA
Cynthia Warner, AuD – Nationwide Children's Hospital, Columbus, Ohio
Julia Webb, AuD – Arkansas Children's Hospital, Little Rock, Arkansas
Louisa Yong Yan Ha, AuD - Thomas Jefferson University Hospitals, Philadelphia, Pennsylvania
Christie Yoshinaga-Itano, PhD – University of Colorado, Boulder, Colorado
Terry Zwolan, PhD – University of Michigan, Ann Arbor, Michigan

Note. The Pediatric Minimum Speech Test Battery (PMSTB) working group consisted of 56 clinicians and researchers from across the United States. Kristin Uhler served as the chair of the working group. René Gifford and Andrea Warner-Czyz acted as co-chairs of the working group.

Acknowledgement
We appreciate the support of Dr. John Niparko and the organizing committee of the 12th International Cochlear Implants and Other Implantable Auditory Technologies in Baltimore, who allowed us to distribute the initial survey that motivated the need to develop this protocol. We feel confident that implementation of the PMSTB will extend Dr. Niparko's mission to detail development of communication skills in children with hearing loss with an end goal of maximizing the auditory potential for children with hearing loss.

INTRODUCTION

This manual provides background on the tests that comprise the Pediatric Minimum Speech Test Battery (PMSTB) and instructions on preparation and administration of these measures. Please refer to the manuscript for background and rationale for a PMSTB

Figure 1 illustrates the administration flow of the test battery both within and across test sessions. The PMSTB includes stopping criteria for tests (<25%) in white boxes, continuation of testing (25-79%) in grey boxes, and ceiling scores (≥80%) in black boxes. Each test is listed in order of difficulty, and the arrows indicate the next test in the hierarchy based on performance. For example, if a child's performance exceeds 79% on the ESP monosyllable task, the child has reached ceiling performance level and should transition to the PSI word test. However, if a child scores <25% on the ESP monosyllables, then the clinician should select an easier auditory task, the ESP spondees. Each testing session should include at least one word and one sentence recognition task, if possible, administered in that order. That way, documentation of a child's progress remains consistent over time.

Select tests based on language level, not chronologic age

Choosing which measure to begin with sometimes presents a challenge because the chronologic age of children with hearing loss often exceeds his or her language age. That is, the language level of a child with hearing loss might reflect age-matched peers, but likely mirrors chronologically younger children. To select an appropriate speech perception measure, clinicians can consult Table 1, which provides information on language performance based on chronologic age, language milestones, and suitable assessment measures for both language and speech perception.

Complete multiple types of tests

The working group endorses completing multiple types of tests (e.g., word and sentence measures) per session, but also recognizes that attaining a complete battery may take multiple sessions. The recommended protocol includes two intensity levels for speech in quiet (conversational speech – 60 dBA; soft speech – 50 dBA; Olsen, 1998; Pearsons et al, 1977) and a higher intensity level for speech in noise (65 dBA) to approximate higher speech levels observed in the presence of background noise (Pearsons et al, 1977). Table 2 summarizes the three listening conditions (i.e., conversational speech in quiet, soft speech in quiet, and higher conversational speech in noise), and three listening configurations (i.e., single device, bilateral devices, and device(s) plus FM/DM system). The endorsed method of administration for this protocol includes recorded materials. However, if a child cannot complete a task, the clinician may revert to an easier task (i.e., monitored live voice) based on professional clinical judgment (Smeds et al, 2015; Uhler et al, 2016).

The PMSTB recommends testing not only in quiet, but also in noise because (a) speech perception performance in quiet does not necessarily translate to speech perception in noise; and (b) children spend the overwhelming majority (approximately 80%) of their awake/listening time in noisy environments (e.g., school classroom, school cafeteria, playgrounds, etc.) (Crukley et al., 2011). The working group selected speech in noise testing with an SNR of +5 dB in an effort to increase the ecological validity of the clinical assessment with a representative of SNRs encountered in everyday listening environments (Pearsons et al., 1977; Smeds et al., 2015). Occupied classroom noise ranges from 48 to 71 dBA (e.g., Sanders, 1965; Nober and Nober, 1975;Bess et al, 1984; Finitzo-Hieber, 1988; Crukley et al, 2011). Children's median equivalent continuous noise level over 24 hours (or Leq) ranges from 60 to 75 dBA (Pearsons et al, 1977; Crukley et al, 2011), depending on the age of the child. With typical noise levels in this range, the average SNR that one would expectedly encounter would be +3 to +5 dB (Pearsons et al, 1977). Thus, in order to gauge real-world performance for speech understanding in noise, the PMSTB recommends a starting SNR of +5 dB. Rather than designing a test battery that would yield high performance levels for most children, the PMSTB stimuli and associated protocol were designed to gauge how well a child was performing in conditions that are most frequently encountered in his or her everyday environment—including conversational and soft speech levels as well as speech in noise at an ecologically valid SNR.

Two conditions exist in which a clinician should use an SNR other than +5 dB. First, if a child cannot perform the task, the clinician should increase the SNR to +10 dB, but only after attempting +5 dB. This exercise will provide the clinician with valuable information regarding progress with the chosen intervention and for guiding recommendations regarding the need for additional services and listening devices. For example, documenting poor speech perception in noise provides baseline evidence supporting the need for an FM/DM system or environmental modifications at school. Second, the clinician should use an SNR other than +5 dB when the individual test procedures indicate otherwise (e.g., Pediatric Speech Intelligibility test).

Follow-up testing based on recommended protocols

In addition to providing recommendations for testing conditions, set-up, and listening configurations, the PMSTB protocol suggests a specific schedule for frequency of follow-up visits for pediatric hearing aid and cochlear implant users (Table 3). The proposed timetable of follow-up visits represents guidelines for standard pediatric audiological care. However, follow-up visits should occur as frequently as needed if a child's performance does not meet expectations or declines considerably—such as cases in which the child has risk factors for otitis media with effusion, or if the child has risk factors for progressive hearing loss (JCIH, 2000, 2007; Warner-Czyz, 2009; Uhler & Gifford, 2014).

Assess clinical significance of a change in scores

The question arises as to what constitutes a clinically significant change. Thibodeau (2006) created Speech Recognition INTerpretation (SPRINT) charts for 25-word and 50-word lists to illustrate the degree of difference required to represent a clinically significant change in adults based on a binomial distribution model (e.g., Thornton and Raffin, 1978). What constitutes a significant change at the individual level depends on the reference starting point on the performance intensity (PI) function. For example, according to the SPRINT chart for a 25-word list, a 20-percentage point decline in speech perception performance from 96% to 76% correct indicates a significant change whereas a decline from 80% to 60% correct does not. The degree of difference constituting a significant individual difference depends on many factors including the reference starting point (in percent correct), the number of items per list, and the individual speech measure itself (Etymotic Research, 2005; Spahr et al. 2014).

The PMSTB working group recommends administration of full lists whenever possible because development and validation of all measures emerged from experimentation with full lists. Therefore, clinicians should pay attention to both the list length and scores obtained over time to determine whether a significant change has occurred. Many of the PMSTB measures, however, lack test-retest variability data as collected in either the typically developing pediatric population or in children with hearing loss. Thus we do not have a SPRINT chart nor consistent normative data for recorded stimuli at 60 dBA for all measures (please see test description sections for details). We recognize this as a limitation of this initial PMSTB and thus encourage clinicians and researchers to collect normative data across the pertinent age range for the documentation of PMSTB norms over time.

The LittlEARS (Coninx et al, 2009) parent report questionnaire can track month-by-month progress on auditory skills development for younger children. The lack of a behavioral measure assessing early auditory skills highlights the need for a normative or criterion-referenced clinical measure that can determine appropriate month-for-month progress for all relevant age groups in both the pre- and post-intervention period.

Figure 1. Recommended protocol for minimum pediatric speech perception battery

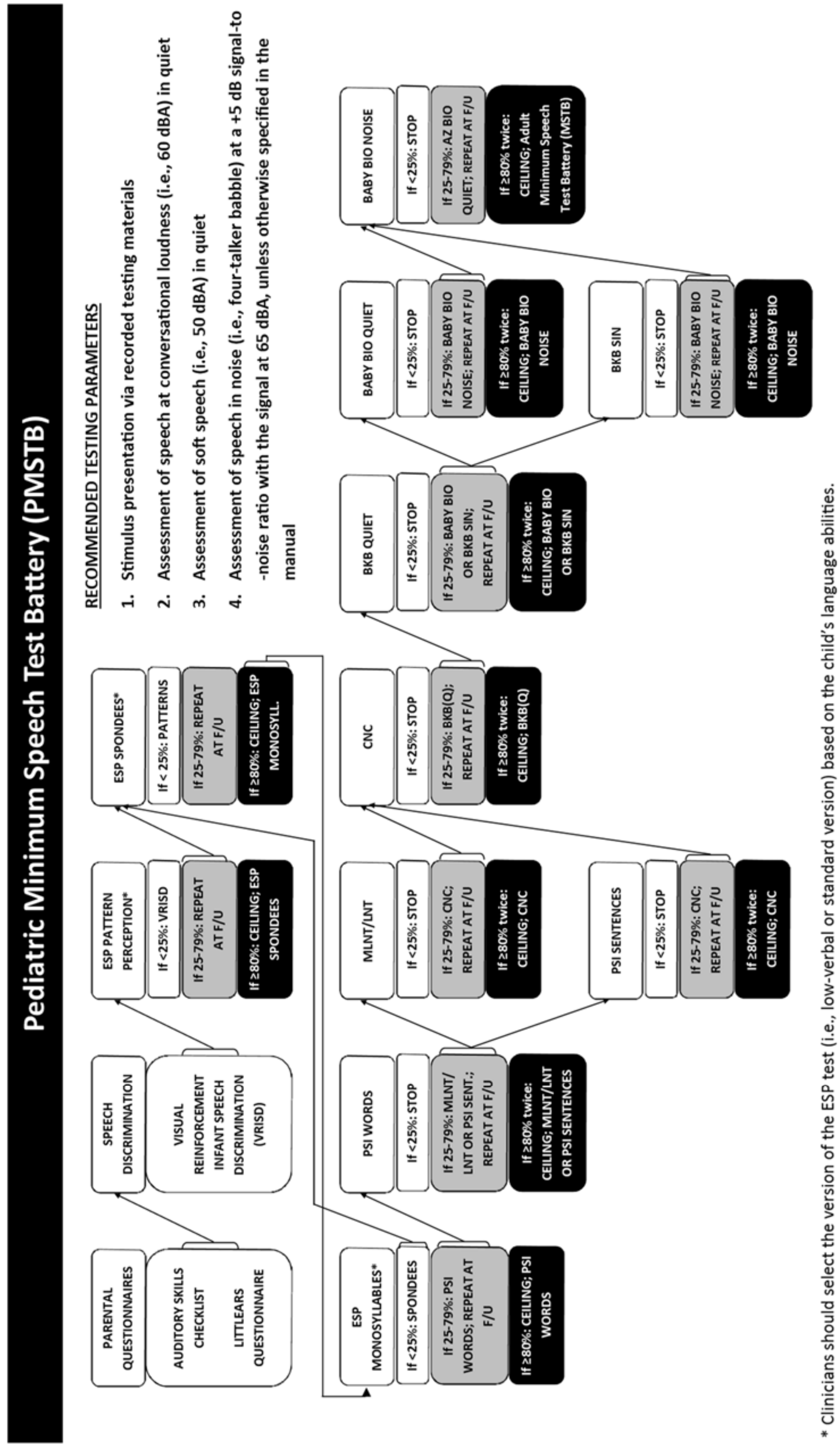


Table 1. Guidance for Test Selection for Estimated Language Abilities Based on Chronologic Age

Age (months)	Receptive Language	Expressive Language	Appropriate Language Measures		Appropriate Speech Perception Tests
			Instrument	Score range	
6-12	Single words; short phrases	N/A	MBCDI: WG	Receptive: 21-74; Expressive: 0-3	1. Parent report
			Rossetti	Criterion-referenced	
			ROWPVT	SS: 85-115	2. VRISD
			EOWPVT	SS: 85-115	
			REEL-3	SS: 85-115	
12-18	Simple phrases and body parts	Single words	MBCDI: WG	Receptive: 74-260; Expressive: 3-94	1. SRT
			MBCDI: WS	52-86 words (expressive)	2. VRISD
			Rossetti	Criterion-referenced	
			PLS-5	SS: 85-115	
			REEL-3	SS: 85-115	
18-24	Follows 2-part instruction	Single words	MBCDI: WS	Expressive: 86-297	1. SRT
			Rossetti	Criterion-referenced	2. VRISD
			PLS-5	SS: 85-115	
			REEL-3	SS: 85-115	
24-36	Follows 2-part instruction	2-3 word combinations	MBCDI: WS	Expressive: 297-548	1. SRT
			Rossetti	Criterion-referenced	2. ESP (low verbal)
			PLS-5	SS: 85-115	
			REEL-3	SS: 85-115	
36-48	Follows 2-3-part instructions	3-word sentences	PLS-5	SS: 85-115	1. ESP (standard)
			OWLS-II	SS: 85-115	2. PSI words,
			CASL	SS: 85-115	3. MLNT
48-60	Follows simple instructions	3-5 word sentences	PLS-5	SS: 85-115	1. LNT
			OWLS-II	SS: 85-115	2. CNC
			CASL	SS: 85-115	
>60	Follows 3 commands	Mostly correct grammar	PLS-5	SS: 85-115	1. BKB (quiet)
			OWLS-II	SS: 85-115	2. BKB-SIN
			CASL	SS: 85-115	3. BabyBio

Note. MBCDI = Macarthur-Bates Communicative Developmental Inventory; Rossetti = Rossetti Infant-Toddler Language Scale; ROWPVT = Receptive One-Word Picture Vocabulary Test; EOWPVT = Expressive One-Word Picture Vocabulary Test; REEL-3 = Receptive-Expressive Emergent Language test, Third edition; PLS-5 = Preschool Language Scales, Fifth edition; OWLS-II = Oral and Written Language Scales, Second Edition; CASL = Comprehensive Assessment of Spoken Language; ASC = Auditory Skills Checklist; VRISD = Visually Reinforced Infant Speech Detection; ESP = Early Speech Perception test; PSI = Pediatric Speech Intelligibility; MLNT = Multisyllabic Lexical Neighborhood Test; LNT = Lexical Neighborhood Test; CNC = Consonant-Nucleus-Consonant test; BKB Quiet = Bamford-Kowal-Bench test in quiet; BKB-SIN = Bamford-Kowal-Bench Speech in Noise test. Scores for MBCDI reflect 50th percentile scores for each age group. Score range based on normative data from typically developing children within each chronologic age group.

Table 2. Recommended testing conditions, set-up, and configurations

Listening condition	Set up	Listening configuration
Conversational level in quiet	60 dBA	Individual ear Bilateral/Bimodal
Low level in quiet	50 dBA	Individual ear Bilateral/Bimodal
Conversational speech in noise	+5 dB signal-to-noise ratio* Signal: 65 dBA	Individual ear Bilateral/Bimodal

	Noise: 60 dBA Both stimuli at 0º azimuth	Device + FM/DM system

Note: The recommended protocol includes three intensity levels (i.e., conversational speech, quiet – 60 dBA; conversational speech, noise – 65 dBA; “soft speech” – 50 dBA) and three listening configurations (i.e., single device, bilateral devices, device(s) plus FM/DM system).

* For the Pediatric AzBio, administer stimuli at +5 dB SNR. The BKB-SIN has an automated SNR. If the child is unable to complete the test at this SNR, a more favorable SNR of +10 dB is recommended; however, +5 dB SNR is the recommended starting point to approximate real-world listening conditions.

Table 3. Recommended frequency of follow-up visits

Duration of device use	Device type: Hearing aid	Device type: Cochlear implant
0 to 1 year	Every 3 months	Every 2-3 months
1 to 2 years	Every 3 months	Every 6 months
2 to 3 years	Every 3 months	Every 6 months
3 to 5 years	Every 6 months	Every 12 months
> 5 years	Every 12 months	Every 12 months

Note: The guidance set forth for the hearing aid follow up is based on Joint Commission on Infant Hearing (JCIH) guidance (2000; 2007) and the cochlear implant follow up is standard of care amongst cochlear implant professionals (JCIH, 2000, 2007; Warner-Czyz, 2009; Uhler & Gifford, 2014). The recommended frequency of follow-up visits presented in this table represents guidelines for standard pediatric audiological care although professionals should use their clinical judgment to determine the necessity of more frequent visits.

ROOM SET-UP AND CALIBRATION

The patient should sit at a distance from the loudspeaker between the near/far field boundary and the critical distance. For many typical audiometric booth sizes, this occurs approximately 1 to 1.2 meter from the soundfield (SF) speaker. Testing in the SF requires calibration of both the input and output of the audiometer. Always begin with calibration of the input level, followed by calibration of the output level.

Calibrating the input level

Calibrating the input level requires a CD with speech materials or digitized speech stimuli stored on a computer or digital music player. Calibration should occur for each test prior to administration.

1. Set the audiometer to external A or B, as appropriate for the input source connected to CD player or your input line if using digitized speech stimuli.
2. Select “speaker” for the transducer.
3. Play the calibration tone (typically a 1,000-Hz tone), adjusting the sensitivity dials for external A and/or B so the VU meter reaches 0 (or just below 0) to avoid distortion of the incoming or input signal. <u>**Do not manipulate the dials after adjusted for input level.**</u>

Calibrating the output level

Output calibration for SF requires a sound level meter (SLM). Ideally, calibration of the output level should occur daily.

1. Place the SLM in the approximate position of the listener’s head using a stand or an extension cable. Using an extension cable allows the SLM to be placed in the control room next to audiometer, making it easier for daily calibration prior to audiologic testing by minimizing the need for the experimenter to move back and forth from the control room and test booth to verify the output level indicated on the SLM.
2. Play the calibration noise that accompanies speech stimuli on CD or via a WAV or MP3 stimulus for SF calibration.
3. Set the weighting on the SLM to *A weighting* and *slow time weighting*. Adjust the dial of the audiometer in 1-dB steps until you are able to record the audiometer dial settings yielding **60dBA ± 1 dB** and **50 dBA ± 1 dB** on the SLM for presentation in quiet and **65 dBA ± 1 dB** for presentation in noise.

NOTE: An additional calibration cross-check would involve presentation of the PMSTB stimuli in the SF while monitoring the SLM to document that the desired calibration level has been achieved.

Calibration for specific tests: Visual Reinforced Infant Speech Discrimination (VRISD)

Route sound files (.wav format) through the commercially available system. Present stimuli via headphones or loudspeakers placed at either 90° or 180° azimuth allowing for a full head turn. To verify routing:

1. Make sure audiometer routing (right or left) matches routing of contrast and video reinforcement (right or left).
2. Calibrate each sound file ensuring no more than 2-dB difference between each sound file.
3. Clinicians can assess multiple levels (i.e., 70, 60, and 50 dBA). As intensity decreases, the level of difficulty will increase. For newer listeners, a higher intensity level may lead to a greater likelihood of meeting criterion for a given phonemic contrast.

PARENT REPORT MEASURES

Auditory Skills Checklist (ASC)
LittlEARS

This section describes two measures of auditory behavior based on parental report, the Auditory Skills Checklist and the LittlEARS questionnaire. Both offer an opportunity to assess auditory behaviors from detection through comprehension in a pediatric population with a broad range of language capacities, from pre-lexical to competent language skills.

AUDITORY SKILLS CHECKLIST (ASC)	
Skills tested:	Detection through comprehension; parent report
Typical chronologic age range:	Birth to 18 years
Language level needed:	Pre-lexical to competent language

The Auditory Skills Checklist© (ASC), a criterion-referenced evaluation tool, aims to assess and track a child's auditory abilities over time (Meinzen-Derr et al, 2007). A 35-item checklist used by the evaluator relies on both the family's and the clinician's observations of a child's auditory skills. Items on the ASC monitor a continuum of auditory skill development from detection to discrimination, identification, and comprehension, mirroring Erber's (1982) depiction of auditory stages. Questions probe multiple skill levels, ranging from basic skills such as wearing amplification during all waking hours to more advanced skills such as understanding most conversational speech through audition alone. The ASC takes about 10 minutes to complete, though younger patients or those with limited auditory skills may finish the questionnaire more quickly.

Test Administration

Evaluators should direct items from the ASC to parents in an interview format versus allowing families to complete the checklist independently. Evaluators can supplement answers by direct observation to document skills that a child has or has not demonstrated in clinical sessions.

Scoring

Evaluators code responses to ASC prompts by the method obtained, frequency of occurrence, and the skill level indicated. The method obtained refers to parental report elicited by case history (H) or direct observation by the evaluator (O). The frequency of occurrence ranges from never or rarely to sometimes to often. The ASC manual offers item-specific interpretations to help the interviewer understand the connection between frequency of occurrence and skill level. For instance, the item inquiring if a child can follow one-step directions denotes that the child has the skill (S) if he or she can follow at least 10 one-step directions; has an emerging skill (E) if he or she can follow at least 3 one-step directions; and does not have the skill (D) if he or she cannot complete this task. The skill level reflects if a child does not have the skill (D), has an emerging skill (E), or has the skill (S), with the potential of 0, 1, or 2 points, respectively (Table 4). Raw scores range from a minimum of 0 to a maximum of 70 points.

Table 4. Scoring of the Auditory Skills Checklist

Frequency of occurrence	Skill Level	Coding	Value/score
Never or rarely	Does not have the skill	D	0
Sometimes	Emerging skill development	E	1
Often	Consistently demonstrates skill (developed)	S	2

Recommended administration of the ASC to track a child's auditory development includes baseline information with follow-up every three months, although evaluators can assess the ASC more frequently if concerns arise about regression of skills or progression of hearing loss. Frequent assessment via the ASC does not affect its validity because the skills assessed cannot be learned through administration alone.

Clinicians can assess performance as both an absolute score and a relative score (i.e., change in scores over time). For example, limited progress over a 3-month period may indicate a need for alternative therapeutic approaches, device settings, or device type (e.g., consideration for a cochlear implant). Furthermore, a consistent administration schedule may help identify regression or a loss of skills over time – an early indicator of worsened hearing loss or device failure. Finally, the clinician can compare skills reported by the parent and the evaluator to judge consistency across respondents.

Considerations

Discontinue use once the child approaches ceiling performance (i.e., ≥80%).

LITTLEARS	
Skills tested:	Detection through comprehension; parent report
Typical chronologic age range:	Birth to 2 years

Language ability: Pre-lexical to competent language

The LittlEARS auditory questionnaire (Weichbold, Tsiakpini, Coninx, & D'Haese, 2005; Coninx et al., 2009) includes 35 yes/no questions that assess auditory-based responsiveness to different sounds and environments. The LittlEARS employs a hierarchical progression of difficulty such that testing terminates after six consecutive 'no' answers. The LittlEARS was designed and normed for infants and children (<24 months) with normal hearing; thus, it is considered useful for children with up to 24 months of implant experience.

Test Administration

Parents can independently complete the LittlEARS questionnaire in 5 to 7 minutes. The age-dependent, hierarchical order of the items eliminates the need to re-administer items for auditory behaviors already demonstrated by the child (per parent report), thereby allowing follow-up on dormant or emerging auditory behaviors.

Scoring

Each "yes" answer receives a score of 1, meaning raw scores range from 0 to 35. The LittlEARS auditory questionnaire includes a scoring chart with age on the x-axis and score on the y-axis that shows average scores for typically developing children with normal hearing along with the 95% confidence interval. Professionals can plot an individual child's score by chronologic age and/or hearing age to determine if a child's development of auditory milestones matches that of hearing peers (i.e., scores falling within the 95% confidence interval) or lags behind hearing peers (i.e., scores falling within the shaded region).

Considerations

Though the LittlEARS generally provides guidelines for children up to 24 months following after initial hearing aid fitting or implant activation, a typically developing child implanted early using processors full time may achieve ceiling performance levels before this time.

Discontinue use once the child approaches ceiling performance (i.e., ≥ 80%).

SPEECH DISCRIMINATION MEASURES

Visual Reinforcement Infant Speech Discrimination (VRISD)

VISUAL REINFORCEMENT INFANT SPEECH DISCRIMINATION (VRISD)	
Skills tested:	Discrimination; open-set
Typical chronologic age range:	6 to 24 months
Language ability:	Pre-lexical to two-word phrases

Visual Reinforcement Infant Speech Discrimination (VRISD), also known as the conditioned head turn procedure, has contributed broadly to our knowledge about early language acquisition, auditory development, and speech perception development in young children with normal hearing (e.g., Moore et al, 1975; Eilers et al, 1977; Nozza, 1987). Several research groups have used the VRISD paradigm to assess perception of minimal pairs, tones, frequency, and intensity in infants with hearing loss (Schauwers et al, 2004; Govaerts et al., 2006; Martinez, 2008; Uhler, Yoshinaga-Itano, Gabbard, Rothpletz, & Jenkins, 2011). In addition, several groups have implemented this methodology clinically to determine cochlear implant candidacy and evaluate cochlear implant fittings (Schauwers et al, 2004; Govaerts et al, 2006; Govaerts et al, 2010) as well as to monitor progress in children with hearing aids (Uhler et al 2011a; Uhler, 2014).

The working group fully acknowledges that most clinical settings do not use VRISD despite its availability for purchase and implementation. However, guidelines for use and normative data available exist for this age group (Govaerts et al, 2006; Uhler et al, 2015). VRISD allows clinicians to assess speech discrimination in infants and toddlers in a manner that does not require linguistic knowledge. This behooves device fitting in two primary ways. First, knowledge of discrimination abilities, validation of amplification fitting for fine tuning is not possible until the child reaches at least 2 years of age, due to other standardly available tests. Second, because clinicians initially fit amplification based on physiological thresholds rather than behavioral thresholds, fittings may not provide details on auditory access to specific phonemes. VRISD assessment can validate that the amplification fitting provides access for phoneme discrimination of the native language. Continued research will enhance the utility and procedures for optimal clinical value.

VRISD depends on the conditioned head turn used in visual reinforcement audiometry (VRA), making it ideal for use with infants between 6 and 24 months of age. If a child can complete a VRA task, then he or she can complete a VRISD task. However, the VRISD task presents a more challenging condition – detection of a *change* in sound – compared to VRA, which simply requires the child to detect *presence* of sound. The increased difficulty of the VRISD task may require more auditory experience prior to completing the task. Several studies have explored auditory discrimination on several sound contrasts. Infants generally discriminate vowel contrasts (i.e., */a-i/, /a-u/, and /u-i/*) more easily and earlier than contrasts that vary by voice onset time (i.e., */ta-da/ and /pa-ba/*) or place of articulation (i.e., */ba-da/ and /pa-ka/*) (Eilers, Wilson, & Moore, 1977; Eilers, Morse, Gavin, & Oller, 1981; Boothroyd, 1984; van Wieringen & Wouters, 1999; Uhler et al., 2011b; Warner-Czyz & Sweeney, 2013).

Test administration

VRISD employs operant conditioning by reinforcing an infant's head turn to a correct response via a mechanical toy or a brief video. Begin by training the child with easy contrasts such as (/a-i/) at a higher intensity such as 70 dBA (Uhler et al, 2015). Once the child reaches criterion (≥ 0.75 proportion correct), proceed to more difficult contrasts as attention allows. Also, the clinician can vary intensity to a level equivalent to soft conversational speech.

1. Select one set of minimal pairs (i.e., /a/-/i/, /a/-/u/, /u/-/i/, /ta/-/da/, or /ba/-/da/).
2. Select one stimulus to serve as background and the other as the contrast.
3. Begin playing the background stimulus before the child and caretaker enter the room to help expedite the child's habituation to the background stimulus.
4. Instruct the caretaker not to cue the child but to provide social praise for a correct response.
5. Initiate a trial once the child is "centered."
6. Condition the infant to make a head turn toward the reinforcer when the stimulus changes (e.g., from the background /*a*/ to the target /*i*/).
7. During the *training phase*, the video will play in conjunction with the change contrast to shape the head-turning behavior. Successful completion of 3 independent head turns in response to a change in contrasts ensures adequate conditioning to begin the test phase.
8. The *testing phase* will include both change (e.g., */a-i-a-i/)* and control (e.g., /*a-a-a-a*/) trials. The clinician indicates *all* head turns when the child turns toward the reinforce – not just with change trials. The software tracks all head turns (see table 5), but the child will only be rewarded when a correct head turn is made in response to a change in sound stimuli.
9. Discontinue testing after completion of a predetermined number of trials (e.g. 15 trials).

Scoring

Score VRISD using proportion correct, which accounts for the number of *hits* (correct identification via a head turn of the change in stimuli), *misses* (no head turn with a change in sound stimuli), *false positives* (head turn when no change has occurred) and *correct rejections* (no head turn when there has not been a change in sound stimuli) (See Table 5).

Table 5. Two-alternative forced choice paradigm used in VRISD

		Signal	
		Present	**Absent**
Infant response	**Yes**	*Hits*	False positives
	No	Misses	*Correct rejections*
	Total number of trials per signal type	Hits + misses	False positives plus correct rejections

Note. Correct responses to the stimuli, shown on the diagonal in italics, include hits and correct rejections.

Calculate proportion correct as follows:

1. Determine the *ratio of correct responses with a present signal* by dividing the number of hits by the total number of trials in which the signal was present (i.e., sum of hits and misses).
2. Determine the *ratio of correct responses with an absent signal* by dividing the number of correct rejections by the total number of trials in which the signal was absent (i.e., sum of false positives and correct rejections).
3. Calculate the *proportion correct* by adding the ratios of correct responses, calculated in steps 1 and 2, and dividing that number by 2. This mathematical process is captured in the following equation: P(C) = [(hits/hits+ misses) + (correct rejection/correct rejection+ false positives)]/2.
4. This yields the proportion correct. Infants who achieve a proportion correct of $\geq$0.75 or greater are considered to have reached criterion for the phoneme contrast (Nozza, 1987; Fredrickson, 2010) for VRISD.
5. Example of calculation of proportion correct with VRISD using data in Table 6:
    a. *Ratio of correct responses with a present signal.* In this example, we divide the number of hits (10) by the total number of hits + misses (13) in which the signal was present to yield the ratio of correct responses with a present signal (10/13 = 0.769).
    b. *Ratio of correct responses with an absent signal.* In this example, we divide the number of correct rejections (12) by the total number of trials in which the signal was absent (15) to yield the ratio of correct responses with an absent signal (12/15 = 0.8).
    c. *Proportion correct*. In this example, we add the ratios of correct responses, calculated in steps 1 and 2 (0.769 + 0.8 = 1.569). Then, divide that sum by 2 to yield the proportion correct (1.569/2 = 0.7845).
    d. Because the proportion correct exceeds 0.75, we can consider the infant met criterion for this particular stimulus contrast.

Table 6. Example data from a two-alternative forced choice paradigm used in VRISD

		Signal	
		Present	**Absent**
Infant response	**Yes**	Hits = 10	False positives = 3
	No	Misses = 3	Correct rejections = 12
	Total number of trials per signal type	Hits + misses = 13	False positives plus correct rejections = 15

Considerations

A child must have head control and be able to complete VRA. When a child has mastered conditioned play audiometry they should be transitioned to the ESP Low Verbal.

WORD RECOGNITION MEASURES, CLOSED-SET

Early Speech Perception (ESP), Low verbal version
Early Speech Perception (ESP), Standard version
Pediatric Speech Intelligibility (PSI) Words

EARLY SPEECH PERCEPTION (ESP), LOW VERBAL VERSION	
Skills tested:	Auditory discrimination; closed-set
Typical chronologic age range:	2 to 5 years
Language level needed:	Pre-lexical to competent language

The Central Institute for the Deaf's *Early Speech Perception* test (ESP; Moog & Geers, 1990) represents one of the most well-known closed-set speech perception tests normed for young children (two years and older) with profound hearing loss prior to newborn hearing screenings. Moog and Geers (1990) designed the ESP to assess speech perception via pattern perception, spondee recognition, and monosyllabic word identification in children with hearing loss who have limited linguistic and language skills. Clinicians can use the test not only to evaluate emergence of perceptual skills, but also to establish objectives for auditory training, measure effects of auditory training, and compare effectiveness of auditory prosthesis options. The ESP test battery takes about twenty minutes to administer.

Description of the three subtests

The *pattern perception subtest* assesses a child's ability to differentiate words based on number of syllables and stress patterns via four types of word patterns: Monosyllabic words (e.g., *ball*), spondaic words (e.g., *airplane*), trochaic words (e.g., *cookie*), and tri-syllabic words (e.g., *birthday cake*).

The *spondee word identification subtest* of the ESP evaluates a child's ability to differentiate two-syllable items with equal stress and effort on each syllable but different consonant and vowel composition (e.g., *hotdog* and *bathtub*).

The *monosyllabic word identification subtest* of the ESP examines a child's ability to distinguish among one-syllable words that share the same initial consonant (e.g., /b/) and similar final consonants (e.g., typically plosives) but differ in the medial vowel (e.g., *bat* vs. *boot*), thereby requiring finer vowel discrimination.

Test administration

The low-verbal version of the ESP provides a format to estimate speech perception abilities in very young children with limited verbal abilities. This version includes a box of 18 toys that can be grouped according to the three subtests of the ESP. The child responds to target stimuli by selecting a response from four child-friendly objects. Clinicians typically present the low-verbal version of the ESP battery via monitored live voice. For each subtest, adhere to the following administration instructions:

1. Select four objects, one from each stress pattern category.
2. Train the child by presenting words in random order with both speech reading and audition until the child correctly identifies 6 items.
3. Present each of the 4 items three times in random order.

Scoring

A. Pattern perception subtest (Maximum score: 12; chance performance: 3/12)

1. Mark the box corresponding to the stimulus word and response word in the matrix on the score sheet.
2. *Criteria to administer the next subtest in the battery*: ≥ 8/12 words

B. Spondee word identification subtest (Maximum score: 12; chance performance: 3/12)

1. Mark a + for correct spondee identification and a – for incorrect spondee identification on the score sheet. Make sure to score in the correct column (either audiovisual (AV) or auditory only (A-1 and A-2 columns).
2. *Criteria to administer the next subtest in the battery*: ≥ 8/12 words

C. Monosyllabic word identification subtest

Scoring of the monosyllabic word identification subtest mirrors that of the spondee word identification test described above.

D. Overall scoring of the low-verbal version of the ESP

Performance on the low-verbal version of the ESP is categorized as detection, pattern perception, some word identification and consistent word identification (Table 7).

Table 7. Speech discrimination categories for the ESP-Low verbal version.

Speech discrimination category	**Description**	**ESP test results**
1 – No pattern perception	Detection without ability to discriminate by pattern	PP < 8
2 – Pattern perception	Minimal skills in perceiving speech; discrimination by durational and stress	PP ≥ 8 SWI < 8

	pattern but not by consonant or vowel sounds	
3 – Some word identification	Minimal ability to use spectral or intonational information; discrimination of words with similar durational stress patterns but only with highly differentiable vowels	SWI ≥ 8 MWI < 10
4 – Consistent word identification	Able to use spectral information for discrimination; discrimination of single-syllable words with differing primarily in vowel sounds	MWI ≥ 10

Note. ESP = Early Speech Perception test battery; PP = Pattern Perception subtest; SWI = Spondee Word Identification subtest; MWI = Monosyllabic Word Identification subtest.

Considerations

This test affords information on early perceptual skills in young children with hearing loss. However, many young cochlear implant recipients in a contemporary population quickly surpass the abilities measured in this test battery. Begin with the most challenging auditory skill (e.g., monosyllabic words). If the child can complete the monosyllabic word identification task, then proceed with the next test in the hierarchy (i.e., PSI words). However, if the child cannot score ≥75% on the monosyllabic word task, then revert to an easier task (e.g., spondee words).

EARLY SPEECH PERCEPTION (ESP), STANDARD VERSION	
Skills tested:	Auditory discrimination; closed-set
Typical chronologic age range:	≥ 3 years
Language level needed:	Pre-lexical to competent language

The standard version of the ESP follows the same premise of the low-verbal version, but uses picture identification rather than object identification to assess speech perception. The ESP test battery takes about twenty minutes to administer.

Test administration

The standard version of the ESP includes words easily depicted in pictures and likely identifiable by most children with hearing loss by age 6 years. In this picture identification task, the child selects a response from 12 full-color pictures. The test includes three cards, one for each subtest.

The tester can administer the ESP to match the child's chronologic age, auditory skills, and linguistic abilities via presentation source (e.g., monitored live voice or recorded materials) and presentation modality (e.g., auditory only or auditory-visual). The tester randomly presents each of the 12 items on the picture card twice, so a perfect score on each subtest is 24 correctly categorized words. Stimuli should be presented in quiet.

For each subtest, adhere to the following administration instructions:

1. Review each of the 12 items on the picture card with the child prior to testing.
2. Present each of the 12 items twice in random order.

Scoring

A. Pattern perception subtest (Maximum score: 24; chance score: 6/24)
   1. Mark the box corresponding to the stimulus word and response word in the matrix on the score sheet. The child receives pattern credit for identifying any word in the stress and durational pattern category, regardless of word score (e.g., selects *airplane* for *hotdog*, because both are spondees).
   2. *Criteria to administer the next subtest in the battery:* 17/24 words (71%)

B. Spondee word identification subtest (Maximum score: 24; chance score: 6/24)
   1. Mark a + for correct spondee identification and a – for incorrect spondee identification on the score sheet. Make sure to score in the correct column (either audiovisual (AV) or auditory only (A-1 and A-2 columns).
   2. *Criteria to administer the next subtest in the battery*: 8/24 words (33%)

C. Monosyllabic word identification subtest (Maximum score: 24; chance score: 6/24)

Scoring of the monosyllabic word identification task in the ESP standard version mirrors that of the spondee word identification task described above.

D. Overall scoring

Performance is classified into one of four categories: detection, pattern perception, some word identification and consistent word identification, Table 8.

Table 8. Speech discrimination categories for the ESP-Standard version.

Speech discrimination category	**Description**	**ESP test results**
1 – No pattern perception	Detection without ability to discriminate by pattern	PP < 16
2 – Pattern perception	Minimal skills in perceiving speech; discrimination by durational and stress pattern but not by consonant or vowel sounds	PP ≥ 17 SWI < 8

3 – Some word identification	Minimal ability to use spectral or intonational information; discrimination of words with similar durational stress patterns but only with highly differentiable vowels	SWI ≥ 8 MWI < 13
4 – Consistent word identification	Able to use spectral information for discrimination; discrimination of single-syllable words with differing primarily in vowel sounds	MWI ≥ 13

Note. ESP = Early Speech Perception test battery; PP = Pattern Perception subtest; SWI = Spondee Word Identification subtest; MWI = Monosyllabic Word Identification subtest.

Considerations

This test affords information on early perceptual skills in young children with hearing loss. However, many young cochlear implant recipients in a contemporary population quickly surpass the abilities measured in this test battery. Begin with the most challenging auditory skill (e.g., monosyllabic words). If the child can complete the monosyllabic word identification task, then proceed with the next test in the hierarchy (i.e., PSI words). However, if the child cannot score ≥75% on the monosyllabic word task, then revert to an easier task (e.g., spondee words).

PEDIATRIC SPEECH INTELLIGIBILITY (PSI) WORDS	
Skills tested:	Word recognition; closed-set
Typical chronologic age range:	≥ 3 years
Language level needed:	Single words (vocabulary >100 words) to competent language

The Pediatric Speech Intelligibility (PSI) test, a closed-set test of word and sentence identification, enables the assessment of speech perception abilities across a range of listening conditions in young children ages 3 through 7 years. Clinicians originally used this measure as a diagnostic test to assess peripheral and central auditory function (Jerger, Jerger, & Abrams, 1983). However, use of the PSI has expanded to include the assessment of speech perception in children with hearing loss using hearing aids and cochlear implants (Jerger, Jerger, & Fahad, 1985; Johnson & Winter, 2003; Eisenberg et al., 2006).

Test administration in quiet

The PSI includes monosyllabic words that emerged from the actual responses of 3- to 6-year-old children with normal hearing in response to pictured stimuli (Jerger et al, 1980). The test presents the 20 words in 4 closed sets of 5 items each, presented on Cards 1 *through* 4. All four cards should be used at each test administration[1]. All word targets are preceded by the carrier phrase "Show me..." (e.g., “Show me frog”).

1. Familiarize the child with the stimuli and the task.
    a. Have child label each word or sentence picture by asking “What is this?” or “What’s happening in this picture? <u>Do not label the pictures for child</u>.
    b. Say each of the targets on the card and instruct the child point to the corresponding picture. This ensures the child understands the task and can perform the required motor response.
2. Present each stimulus one time at 60 dBA from the primary speaker directly in front of the child (0° azimuth), starting with Card 1 and ending with Card 4.
3. Instruct the child that he will hear a man (the "show me" man) saying words and that he should point to the picture that matches the word he hears. As an alternative, an older child can repeat the word or call out the number in the lower right corner of the picture corresponding sentence heard.
4. The child should be encouraged to "guess" if they are not certain.

[1] The use of different testing paradigms for PSI words and sentences (i.e., different number of response cards; testing with and without competing stimuli) was intentional in the original test development. These differences in stimuli presentation and pacing between the first and the second task (regardless of the order in which they are administered) are designed to help sustain the young child's attention in the second task (Jerger & Jeger, 1984).

Scoring

Word scores are reported as percent correct identification out of the total of twenty words presented.

1. For those picture cards yielding 100% correct identification, each word correct contributes 5% toward the total score.
2. For those picture cards yielding < 100% correct identification, each word correct contributes 2.5% to the total score.

OPTIONAL: Test administration in the presence of competing noise

If a child scores at least 50% correct words in the quiet condition, professionals can opt to administer the PSI word test in a more difficult listening condition with single-talker competition. We recommend using the PSI contralateral competing message (CCM). Testing should occur at three message-to-competition ratios (MCRs) ranging from relatively easy to relatively difficult (+10, 0, and -10 dB, respectively). Please note that the PSI word task in noise is considered more difficult than the PSI sentences in noise.

1. Prior to the introduction of the competition for the first time, instruct the child that he or she will also hear another man (the "trick man") talking at the same time, but not to let the "trick man" trick them. They are to listen only for the "show me" man and point to what they heard.
2. Begin with the easiest competing condition (e.g., +10 MCR) using the PSI-CCM track. For example, the +10 MCR condition should include a target signal of 60 dBA at 0º azimuth and a CCM intensity of 50 dBA at either 90 or -90 º azimuth.
3. If child scores ≤ 20% at given MCR, stop. Otherwise proceed to the next more difficult MCR.
4. Optional: +20 and -20 MCR (i.e. "very easy" and "very difficult" MCR's).

Considerations

It should be noted that in the Eisenberg and Dirks (1995) recording, the targets and the competing noise are spoken by the same male talker. This may increase the level of difficulty.

WORD RECOGNITION MEASURES, OPEN SET

Multisyllabic Lexical Neighborhood Test (MLNT)
Lexical Neighborhood Test (LNT)
Consonant-Nucleus-Consonant (CNC)

MULTISYLLABIC LEXICAL NEIGHBORHOOD TEST (MLNT)
LEXICAL NEIGHBORHOOD TEST (LNT)

Skills tested:	Word recognition; closed-set
Typical chronologic age range:	≥ 3 years
Language level needed:	Single words (vocabulary >100 words) to competent language

Description

The Lexical Neighborhood Test (LNT) and Multisyllabic Lexical Neighborhood Test (MLNT) (Kirk et al, 1995a) assess word recognition in children with hearing loss and children with limited vocabularies. The Neighborhood Activation Model of spoken word recognition (Luce & Pisoni, 1998) underlies the development of these two perceptual measures. According to the Neighborhood Activation Model, both *word frequency* (i.e., how often words occur in the language) and *lexical density* (i.e., the number of phonemically similar words to the target word) influence spoken word recognition. One measure of lexical similarity is the number of “neighbors,” or words that differ by one phoneme from the target word (Greenberg & Jenkins, 1964; Landauer & Streeter, 1973). For example, the words *bat, cap, cut, scat,* and *at* are all neighbors of the target word *cat*. Words with many lexical neighbors come from “dense” lexical neighborhoods (e.g., *cat*), whereas words with few lexical neighbors come from “sparse” lexical neighborhoods (e.g., *banana*). Previous research shows that high frequency words from sparse neighborhoods (*easy words)* are recognized faster and with greater accuracy than low-frequency words from dense neighborhoods (*hard words*) (Luce, 1986; Luce et al, 1990; Luce & Pisoni, 1998).

Stimuli for the MLNT and LNT came from the transcribed language samples of children between 3 and 5 years of age in the Child Language Data Exchange System (CHILDES) (MacWhinney & Snow, 1985). The aim was to identify target words that would be known by children with profound hearing loss. The MLNT consists of two unique lists of two- to three-syllable words. Each list consists of 12 lexically easy words and 12 lexically hard words. The LNT consists of two unique lists of one-syllable words. Each list consists of 25 lexically easy words and 25 lexically hard words. The MLNT and LNT each take approximately 10 minutes to administer.

Test administration

1. Instruct the child to repeat the word he or she heard using his or her typical form of communication (e.g., if the child uses total communication, then he or she should speak and sign the response).
2. The examiner can ask the child to clarify unintelligible responses (e.g., "What is that?", "What do you do with that?"), but each stimulus will only be presented once.

Scoring

The examiner records each response on the scoring form using either phonemic transcription (e.g., /bənænə/) or orthographic transcription (e.g., *banana*).

1. Calculate two scores: *Percentage of words correctly identified* and *percentage of phonemes correctly identified* for each part of the test (lexically easy words and lexically hard words are scored separately) and for the test as a whole.
2. Give credit for phonemes produced in the order they occur in the target word. For example, if a child responds to the target word *pie* with *put*, then the initial *p* phoneme would be considered correct. If, on the other hand, the child responded with *cap*, the *p* phoneme would not correspond to the correct position in the target word, thus no credit would be given.

The examiner cannot assign credit for responses that are unintelligible even after the examiner asks for clarification. These responses are transcribed phonemically and then scored for phoneme correctness.

Considerations

Scores may reflect articulation rather than perceptual errors. In addition to calculating percent correct scores for phonemes and words, the evaluator can examine error types to extract common patterns (i.e., missing final /s/) that may indicate the need for changes to the device program or emphasis in therapeutic intervention. A limited number of lists for both the MLNT and LNT make it difficult to present in multiple listening conditions (i.e., 2 individual ears plus binaural mode). Thus there is a need for development of additional lists and/or metrics assessing monosyllabic and multisyllabic word recognition for pediatric listeners.

CONSONANT-NUCLEUS-CONSONANT (CNC) WORDS	
Skills tested:	Word recognition; closed-set
Typical chronologic age range:	≥ 5 years
Language level needed:	Single words (vocabulary >100 words) to competent language

The CNC test assesses recognition of monosyllabic words (Peterson and Lehiste, 1962). The test includes 10 lists of 50 words each. A carrier word, “Ready,” precedes each target word. The first three words serve as practice, immediately followed by the first word of the test. Scoring includes calculation of percentage of whole words and/or phonemes that are correctly repeated.

Test administration

1. Instruct the child to repeat the word he or she heard after the word “ready” using his or her typical form of communication (e.g., if the child uses total communication, then he or she should speak and sign the response). Encourage the child to guess.
2. The examiner can ask the child to clarify unintelligible responses (e.g., “What is that?”, “What do you do with that?”), but each stimulus will only be presented once.
3. The recorded speech may be paused until the child responds.

Scoring

The examiner records each response on the scoring form using either phonemic transcription (e.g., /bæt/) or orthographic transcription (e.g., *bat*).

1. Calculate two scores: *Percentage of words correctly identified* and *percentage of phonemes correctly identified* for the test as a whole.
2. Give credit for phonemes produced in the order they occur in the target word. For example, if a child responds to the target word *tack* with *pack* (/pæk/), then the final */k/* phoneme would receive credit as correct because it maintains the final word position of the phoneme. If, on the other hand, the child responded with cat (/kæt/), the */k/* phoneme would not correspond to the correct position in the target word; thus, the child would not receive credit for that phoneme.

The examiner should not assign credit for responses that are unintelligible even after the examiner asks for clarification. Rather, transcribe the responses phonemically and score for phoneme correctness.

Considerations

Scores may reflect articulation rather than perceptual errors. Please keep in mind CNC words were not normed for administration of 25-word lists. It may be necessary to utilize frequent reinforcers to complete the full list.

SENTENCE RECOGNITION MEASURES, CLOSED SET

Pediatric Speech Intelligibility (PSI) sentences

PEDIATRIC SENTENCE INTELLIGIBILITY (PSI) SENTENCES	
Skills tested:	Sentence recognition; closed-set
Typical chronologic age range:	≥ 3 years
Language level needed:	2- to 3-word sentences

The PSI includes 10 sentences presented in two closed-sets of 5 items each. All test items were generated from the actual responses of normal hearing children between the ages of 3 and 6 years in response to pictured stimuli (Jerger et al, 1980).

To control for differences in chronological age, vocabulary skills, and receptive language abilities, two types of sentence materials (format I and format II) were developed. The two formats differ in the use of a carrier phrase (*Show me*). Format I more closely represented the typical production patterns exhibited by younger children during test development. Format II more appropriately depicts typical of the production patterns of children 5 years and older.

Test administration in quiet

1. Familiarize the child with the stimuli. Have the child label each sentence picture by asking "What is this?" or "What's happening in this picture? Do not label the pictures for child. If the child gives you a partial response for the sentence pictures, (e.g. "He's eating"), provide prompts such as asking "Who's eating?" or "What is he eating?" to give the child a chance to label each picture its entirety.[2]
2. Say each of the targets on the selected card aloud and instruct the child point to the corresponding picture. This helps to ensure that the child understands the task and can perform the required motor response.
3. Instruct the child that he or she will hear a man (the "show me" man) saying the sentences in the pictures, and that they are to point to the picture that they heard. As an alternative, older children can repeat the sentence or call out the number in the lower right corner of the picture corresponding sentence heard.
4. The child should be encouraged to guess.
5. Administer the first five items.
    a. If the child cannot correctly identify any sentences, STOP.
    b. If the child correctly identifies all sentences, STOP.
    c. If the child correctly identifies 1 to 4 items, administer the rest of the 10-item list.

---

[2] Familiarization with the pictured targets as outlined above is an important step to ensure that the child is able to "read" the pictures with accuracy and has the vocabulary to do the test. In addition, the child's pattern of response in labeling the pictures can assist in determining the most appropriate sentence format.

Scoring

Report sentences scores as percent correct identification, regardless of number of items per list.

OPTIONAL: Test administration in the presence of competing noise

If a child scores at least 50% correct words in the quiet condition, professionals can opt to administer the PSI sentence test in a more difficult listening condition with single-talker competition. As with the PSI word test in noise, we recommend using the PSI CCM. Testing should occur at three message-to-competition ratios (MCRs) ranging from relatively easy to relatively difficult (+10, 0, and -10 dB, respectively).

1. Prior to the introduction of the competition for the first time, instruct the child that he or she will also hear another man (the "trick man") talking at the same time, but not to let the "trick man" trick them. Listen <u>only</u> for the "show me" man and point to what they heard.
2. Begin with the easiest competing condition (e.g., +10 MCR) using the PSI-CCM track. For example, the +10 MCR condition should include a target signal of 60 dBA presented at 0º azimuth and a CCM of 50 dBA presented at either 90º or -90º azimuth.
3. If child scores ≤ 20% at given MCR, stop. Otherwise proceed to the next more difficult MCR.
4. Optional: +20 and -20 MCR (i.e. "very easy" and "very difficult" MCR's).

Scoring

Scoring sentences in noise are reported as percent correct identification, as a function of MCR.

SENTENCE RECOGNITION MEASURES, OPEN SET

Bamford-Kowal-Bench Sentences in Quiet
Bamford-Kowal-Bench Sentences in Noise (BKB-SIN)
Pediatric AzBio in Quiet
Pediatric AzBio in Noise

BAMFORD-KOWAL-BENCH SENTENCES IN QUIET	
Skills tested:	Sentence recognition, open set
Typical chronologic age range:	≥ 3 years
Language level needed:	2- to 3-word sentences

The BKB consists of 16 sentence lists, each list contains 50 key words. The original sentences derived from natural language samples of children who had hearing loss. The creators of the BKB test recorded utterances from 240 children between 8 and 15 years, then validated the 16 final sentences on 13 children with hearing loss and 11 children with normal hearing (Bench et al, 1979).

Test Administration

Evaluators can administer the BKB test using the sentence track version of the BKB-SIN. We acknowledge the normative data for children between 3 and 5 years of age do not exist, but several clinicians in the PMSTB working group shared that they can obtain reliable test results from children as young as 3 years. Over time, implementation of the PMSTB may make it possible to develop norms for younger age groups.

Scoring

Speech recognition performance on the BKB is determined by the percentage of key words correctly repeated.

BAMFORD-KOWAL-BENCH SENTENCES IN NOISE (BKB-SIN)	
Skills tested:	Sentence recognition; open-set
Typical chronologic age range:	≥ 5 years
Language level needed:	2- to 3-word sentences

The BKB-SIN (Etymotic Research, 2005) uses sentences from the BKB test, described above, and four-talker babble to assess speech recognition in the presence of background noise which varies in signal-to-noise ratio. The BKB-SIN can calculate both the SNR-50, which helps identify the signal-to-noise ratio approximating 50% correct performance, as well as SNR-loss which represents the child's deficit in speech understanding, in dB, relative to hearing peers. The BKB-SIN is quick and easy to use, taking approximately 3 minutes to administer and score.

Test administration

The BKB-SIN contains 18 equivalent list pairs (A and B) with 8 or 10 sentences, each with 3-4 key words per sentence. Testers must administer both lists of the pair for valid scoring. The level of the target talker (a male voice) remains constant as the level of the four-talker babble increases. Signal to noise level starts at +21 dB and decreases to -6 dB on list pairs 1-8 and starts at +21dB and decreases to 0 dB on list pairs 9-18.

1. The prompt "ready" precedes each sentence.
2. Administer one list pair and score for key words correct.
3. Testers can use a half list as a practice list.

Scoring

Each sentence has key words that are underlined on the score sheet.

1. Calculate the total correct number of key words from each list.
2. Subtract that value from 23.5 to obtain the SNR-50 for each list.
3. Average the scores from both lists of the pair for valid scoring.
4. Compare the list pair score to the age-related norms to determine SNR loss (see Table 9).

Table 9. BKB-SIN Test Norms

		Adults		Children (by age)		
	Presentation level	Normal hearing	CI users	5-6 years	7-10 years	11-14 years
Mean SNR-50 (Standard deviation) [a]	70 dB HL via inserts	-2.5 (0.8)	* (1.6)	3.5 dB (2.0)	0.8 dB (1.2)	-0.9 dB (1.1)
Mean SNR-50 [b]	60 dBA sound field			3.1 dB (1.5)	1.2 dB (1.4)	0.2 dB (1.2)

Note. Compare values in cells to normal-hearing adult value to determine SNR Loss with a 70 dB HL presentation level (Etymotic Research, 2005) [a]. The data shown for children in Table 8 were derived from Holder and colleagues (2016) [b] using recorded stimuli presented in the sound field at a calibrated level of 60dBA (Holder et al, 2016). Thus, these methods were directly comparable to clinical assessment of speech understanding for children with hearing loss. In contrast, the normative values appearing in the BKB-SIN manual were obtained using insert earphones with stimuli at 70 dB HL. The "*" indicates that the value should be compared to the normal-hearing adult value to determine SNR loss, the standard deviation of 1.6.

Table 10. 95% critical difference scores on the BKB-SIN test based on age and list

List	Age		
	5-6 years	7-10 years	11-14 years
1	5.4	3.5	3.2
2	3.9	2.5	2.3
3	3.1	2.0	1.9
4	2.7	1.8	1.6
5	2.4	1.6	1.5
6	2.2	1.4	1.3
7	2.1	1.3	1.2
8	1.9	1.2	1.1
9	1.8	1.2	1.1

Note. CD=critical difference (Etymotic Research, 2005) for the BKB-SIN using 70 dB HL via inserts. However, due to the similarities for the means as a result of Holder et al (2016) findings to the Etymotic Research (2005) we feel it is appropriate to use these CD as guidance for detection of differences. For clinical interpretation, the larger number of lists administered leads to a decrease in variability.

Considerations

Per the test booklet, testers should interpret results for children on a case-by-case basis integrated with other tests versus in isolation.

PEDIATRIC AzBIO (BabyBio) IN QUIET AND NOISE	
Skills tested:	Sentence recognition; open-set
Typical chronologic age range:	≥ 5 years
Language level needed:	Second grade language level (based on readability of sentences)

Development of the Pediatric AzBio sentence lists, more commonly known as the "BabyBio" sentence lists, specifically aimed to evaluate children with hearing loss or cases for which adult materials are inappropriate due to difficulty level or content (Spahr et al., 2014). The BabyBio sentence corpus includes 16 lists of equivalent difficulty, each with 20 unique sentences. Sentence length ranges from 3 to 12 words. Unlike the AzBio corpus which has male and female talkers, the BabyBio sentences only include sentences spoken by a single female talker because pilot testing revealed that children's responses were more consistent and reliable when using a female talker. However, future plans include development of a multi-talker version of the BabyBio.

Test administration

1. *Present full lists only.* Present a full 20-sentence list for valid results based on initial testing for list equivalency.
2. *Administer prior to switching to a different technology (e.g., from hearing aids to cochlear implants)*. Administer the BabyBio sentences at pre-operative sessions for older children (~5+ years) to obtain a preoperative baseline.
3. *Post-operative administration.* Track longitudinal progress, efficacy of intervention, and adequacy of assistive technology (e.g. CI + HA, CI + HA + FM, etc.) at regular postoperative intervals.

Scoring

Score each sentence list as percent words correct. Table 11 displays normative data for the BabyBio including mean scores, in percent correct, as well as the 95% confidence intervals for the difference age groups and SNRs tested.

Table 11. Normative data for the Pediatric Bio open-set sentence recognition test.

Signal-to-noise ratio	Age (years) 5-6	7-8	9-10	11-12	Mean (SD)
+ 10 dB	97.7% (95.4-99.9)	99.1% (98.6-99.7)	99.5% (99.1-99.9)	99.6% (99.1-100.0)	99.0 (1.7)
+5 dB	96.0% (91.3-100.0)	98.2% (97.2-99.2)	99.7% (99.5-99.9)	99.4% (98.7-100.0)	98.4 (3.5)
0 dB	92.8% (87.1-98.5)	97.0% (95.8-98.2)	98.9% (98.1-99.6)	98.5% (97.6-99.3)	96.8 (4.6)
-5 dB	81.8% (69.8-93.7)	79.4% (69.2-89.7)	91.1% (87.7-94.4)	85.9% (75.2-96.7)	85.5 (13.7)

Note. Holder et al. (2016) gathered the normative data displayed in this table, which includes the mean percent correct scores and 95% confidence interval by SNR and by age.

Considerations

Clinicians should recognize that the BabyBio only includes 16 lists in the present version. Thus, to avoid learning or familiarity with multiple administrations longitudinally, the pediatric working group recommends recording list numbers to eliminate or at least minimize repetition of lists.

Once a child has reached mastery of the tests in this battery, testing should transition to the Minimum Speech Test Battery (2011) for adult cochlear implant recipients, which lists the use of the BabyBio's adult analog, AzBio, for assessment of sentence recognition.

References:

BenchJ, Kowal A, Bamford J. (1979) The BKB (Bamford-Kowal-Bench) sentence lists for partially-hearing children. *Br J Audiol 13*: 108–112.

Bess FH, Sinclair J, and Riggs D. (1984) Group amplification in schools for the hearing impaired. *Ear Hear 5*: 138–144.

Boothroyd A. (1984) Auditory Perception of Speech Contrasts by Subjects with Sensorineural Hearing Loss. *J Speech Hear Res 27*: 134-144.

Coninx F, Weichbold V, Tsiakpini L, Autrique E, Bescond G, Tamas L. (2009) Validation of the LittlEARS Auditory Questionnaire in children with normal hearing. *Int J of Pediatr Otorhinol 73*: 1761-1768.

Crukley J, ScollieS, Parsa V. (2011) An Exploration of Non-Quiet Listening at School. *J Ed Audiol*, *17*: 23–35.

Eilers RE, Morse PA, Gavin WJ, Oller DK. (1981) Discrimination of voice onset time in infancy. *J Acoust Soc Am 70*: 955-965.

Eilers RE, Wilson WR, and Moore JM. (1977) Developmental changes in speech discrimination in infants. *J Acoust Soc Am 20*: 766-780.

Eisenberg LS, Dirks DD. (1995) Reliability and Sensitivity of Paired Comparisons and Category Rating in Children. *J Speech Lang Hear Res, 38*: 1157-1167.

Eisenberg LS, Johnson KC, Martinez AS, Cokely CG, Tobey EA, Quittner AL, . . . Niparko JK. (2006) Speech recognition at 1-year follow-up in the childhood development after cochlear implantation study: Methods and preliminary findings. *Audiol Neuro-Otol 11*: 259-268.

Erber N. (1982) Erber's levels of auditory functioning: Speech perception skills. In *Alexander Graham Bell Association* 92–94. Washington, D.C.

Etymotic Research. (2005). *Etymotic Research BKB-SIN Speech-in-Noise Test* (Version 1.03). Elk Grove Village, IL: Etymotic Research

Finitzo-Hieber T. (1988) Classroom acoustics. In R. Roeser (Ed), *Auditory disorders in school children* (2nd ed). New York: Thieme-Stratton, 221–223.

Fredrickson T. (2010) Visual Reinforcement Infant Speech Discrimination: Developing a Method of Performance Analysis. Unpublished dissertation. Boulder, CO: University of Colorado.

Govaerts PKD, Yperman M, De Beukelaer CGDS, De Ceulaer G. (2006) Auditory speech sounds evaluation (A§E®): a new test to assess detection, discrimination, and identification in hearing impairment. *Cochlear Implants Int 7*, 97-106.

Govaerts P, Vaerenberg G, Ceulaer G Daemers K, Beukelaer CD, Schauwers K. (2010) Development of a software tool using deterministic logic for the optimization of cochelar implant processor programming. *Otol Neurotol, 6,* 908-918.

Greenberg JH, Jenkins JJ. (1964) Studies in the psychological correlates of the sound system of American English. *Word 20*: 157-177.

Holder JT, Sheffield SW, Gifford RH. (2016) Speech Understanding in Children With Normal Hearing: Sound Field Normative Data for BabyBio, BKB-SIN, and QuickSIN. *Otol Neurotol 37*: e50–5.

Jerger S, Jeger J. (1984) Pediatric speech intelligibility Test. St. Louis, MO: Auditec

Jerger S, Jerger J, Abrams S. (1983) Speech audiometry in the young child. *Ear Hear 4*: 56-66.
Jerger S, Jerger J, Fahad R. (1985) Pediatric hearing aid evaluation: case reports. *Ear Hear 6*: 240-244.
Jerger S, Lewis S, Hawkins J, Jerger J. (1980) Pediatric Speech Intelligibility Test. I. Generation of test materials. *Int J Pediatr Otorhinolaryng 2*: 217–230.
Johnson KC, Winter MA. (2003) Assessment of infants and toddlers with hearing loss. *Volta Rev (Monograph)*: 221-251.
Joint Commision on Infant Hearing (2000) Year 2000 position statement: principles and guidelines for early hearing detection and intervention programs. Joint Committee on Infant Hearing, American Academy of Audiology, American Academy of Pediatrics, American Speech-Language-Hearing Association, and Directors of Speech and Hearing Programs in State Health and Welfare Agencies. *Pediatrics:* 798-817.
Joint Commision on Infant Hearing (2007) Year 2007 position statement: Principles and guidelines for early hearing detection and intervention programs. *Pediatrics 120*:898-921.
Kirk KI, Pisoni DB, Osberger MJ. (1995a) Lexical effects on spoken word recognition by pediatric cochlear implant users. Ear Hear. 16: 470-81.
Kirk KI, Pisoni DB, Sommers MS, Young M, Evanson C. (1995b) New directions for assessing speech perception in persons with sensory aids. Ann Otol Rhinol Laryngol Suppl 166: 300-3.
Kuehn-Inacken H, Weichboldt V, Tsiakpini L, Coninx F, D'Haese P. (2003) LittlEARS Auditory questionnaire: Parents questionnaire to assess auditory behaviour.

Landauer TK, Streeter LA. (1973) Structural differences between common and rare words: Failure of equivalence assumptions for theories of word recognition. *J Verbal Learning Verbal Behav 12*: 119-131.
Luce, P. A. (1986). Neighborhoods of Words in the Mental Lexicon. Research on Speech Perception. Technical Report No. 6.
Luce P, Pisoni D, Goldinger S. (1990) Similarity neighborhoods of spoken words *Cognitive models of speech processing: Psycholinguistic and computational perspectives.* Cambridge, MA, US: The MIT Press, 122-147.
Luce PA, Pisoni DB. (1998) Recognizing spoken words: the neighborhood activation model. *Ear Hear 19*: 1-36.
MacWhinney B, Snow C. (1985) The child language data exchange system. *J Child Lang, 12:* 271-295.
Martinez A, Eisenberg L, Boothroyd A, Visser-Dumont L. (2008) Assessing speech pattern contrast perception in infants: Early results on VRASPAC. *Otol Neuroto 29*: 183-188.
Meinzen-Derr J, Wiley S, Creighton J, Choo D. (2007) Auditory Skills Checklist: clinical tool for monitoring functional auditory skill development in young children with cochlear implants. *Ann Otol, Rhinol Laryngol 116*(11), 812–818.

Minimum-Speech-Test-Battery. (2011) The new minimum speech test battery http://auditorypotential.com/MSTB.html.

Moog J, Geers A. (1990) *Early Speech Perception Test*. St. Louis, MO: Central Institute for the Deaf.
Moore J, Thompson G, Thompson M. (1975) Auditory localization of infants as a function of reinforcement conditions. *J Speech Lang Hear Dis 40:* 29–34.
Nober L, Nober E. (1975) Auditory discrimination of learning disabled children in quiet and classroom noise. *J Learning Disabil*, *8*, 656–659.
Nozza RJ. (1987) Infant speech-sound discrimination testing: Effects of stimulus intensity and procedural model on measures of performance. *J Acoust Soc Am 81*: 1928-1939.
Olsen WO. (1998) Average Speech Levels and Spectra in Various Speaking/Listening Conditions. ***Am J Audiol:*** 7, 21-25.
Pearsons K, Bennet R, Fidell S. (1977) *Speech levels in various environments*. Washington D.C.
Peterson GE, Lehiste I. (1962) Revised CNC lists for auditory tests. *J Speech Hear Disord 27*: 62-70.
Sanders D. (1965) Noise conditions in normal school classrooms. *Exceptional Child 31*: 344–353.
Schauwers K, Gillis S, Daemers K, Beukelaer CD, Govaerts PJ. (2004) Cochlear implantation between 5 and 20 months of age: The onset of babbling and the audiologic outcome. *Otol Neurotol 25*, 263-270.

Smeds K, Wolters F, Rung M. (2015). Estimation of signal-to-noise ratio in realistic sound scenarios. J Am Acad Audiol, 26(2): 183-96.

Spahr A, Dorman M, Cook S, Loiselle L, Hayes C et al. (2014) Development and validation of the pediatric AzBio sentence test. *Ear Hear 35*: 418-422.
Thibodeau LM. (2006) Speech audiometry. In R. Roeser, M. Valente, H. Hosford-Dunn (Eds.), *Audiology: Diagnostics.* New York Thieme Medical Publishers, 288-313.
Thornton AR, Raffin MJ. (1978) Speech-discrimination scores modeled as a binomial variable. *J Speech Hear Res 21*: 507-518.
Uhler, K. (2014) Relationship between speech perception and language. Ultimate Colorado Midwinter Meeting, February 2014.
Uhler K, Gifford RH. (2014) Current trends in pediatric cochlear implant candidate selection and postoperative follow-up. *Am J Audiol 23*: 309-325.
Uhler K, Biever A, Gifford RH. (2016) Method of Speech Stimulus Presentation Impacts Pediatric Speech Recognition: Monitored Live Voice Versus Recorded Speech. Otol Neurotol 37: e70-4.
Uhler KM, Baca R, Dudas E, Fredrickson T. (2015) Refining Stimulus Parameters in Assessing Infant Speech Perception Using Visual Reinforcement Infant Speech Discrimination: Sensation Level. *J Am Acad Audiol 26:* 807–814.
Uhler K, Burns S, Dalpes M, Yoshinaga-Itano C (2011a) An auditory spoken language matrix for differential diagnosis of Spanish-speaking children who are deaf or hard of hearing. Special interest group 14, communication disotrders and sciences in culturally and linguistically diverse populations.
Uhler K, Yoshinaga-Itano C, Gabbard SA, Rothpletz AM, Jenkins H. (2011b) Longitudinal infant speech perception in young cochlear implant users. *J Am Acad Audiol, 22*: 129-142.

van Wieringen A, Wouters, J. (1999). Natural vowel and consonant recognition by Laura Cochlear implantees. *Ear Hear 20*: 89-103.
Warner-Czyz AD. (2009) Initial stimulation and mapping: What to expect. In B. Loy and P. Roland (Eds.), *In Cochlear Implants: What Parents Should Know.* San Diego Plural Publishing, 123-143.
Warner-Czyz AD, Sweeney M. (2013) *Relation between speech discrimination and word onset in young cochlear implant recipients*. Paper presented at the Cochlear Implant 2013 Symposium: Emerging Issues in Cochlear Implantation, Washington, D.C.
Weichbold V, Tsiakpini L, Coninx F, D'Haese P. (2005) Development of a parent questionnaire for assessment of auditory behaviour of infants up to two years of age. *Laryngo-rhino-otolog, 84*(5).

Appendix A
Details for ordering specific test measures.

Test	Authors (year)	Ordering/ download information
Auditory Skills Checklist (ASC)	Meinzen-Derr, Wiley, Choo, and Creighton (2004)	Annals of Otology, Rhinology, and Laryngology, 116(11), 812-818.
Bamford-Kowals-Bench (BKB) Sentences in Quiet and in Noise (BKB-SIN)	Bench, Kowals, Bamford (1979) - BKB quiet; Etymotic Research (2005) - BKB-SIN	Auditec (www.auditec.com) Etymotic Research (www.etymotic.com)
Consonant-Nucleus-Consonant (CNC)	Peterson and Lehiste (1962)	Bio-logic Systems Corp. (http://www.bionicear.com/For_Professionals/Audiology_Support/CNC_Test.cfm?)
Early Speech Perception Test	Moog and Geers (1990)	Central Institute for the Deaf (http://www.cid.edu/ProfOutreachIntro/EducationalMaterials.aspx)
Lexical Neighborhood Test (LNT)	Kirk, Pisoni, and Osberger (1995)	Auditec (www.auditec.com)
LittlEars Auditory Questionnaire	Kuhn-Inacker et al, (2003)	Med El (http://s3.medel.com/downloadmanager/downloads/bridge_us/en-US/BRIDGE_Order_Form.pdf)
Multisyllabic Lexical Neighborhood Test (MLNT)	Kirk, Pisoni, and Osberger (1995)	Auditec (www.auditec.com)
Pediatric AzBio Sentence Lists	Spahr, Dorman, Litvak, Cook, Loiselle, DeJong, Hedley-Williams, Sunderhaus, Hayes, Gifford (2014)	Auditory Potential (http://www.auditorypotential.com/purchase.html)
Pediatric Speech Intelligibility (PSI)	Jerger and Jerger (1984)	Auditec (www.auditec.com)