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Tutorial

Pediatric Minimum Speech Test Battery

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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

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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.

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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.

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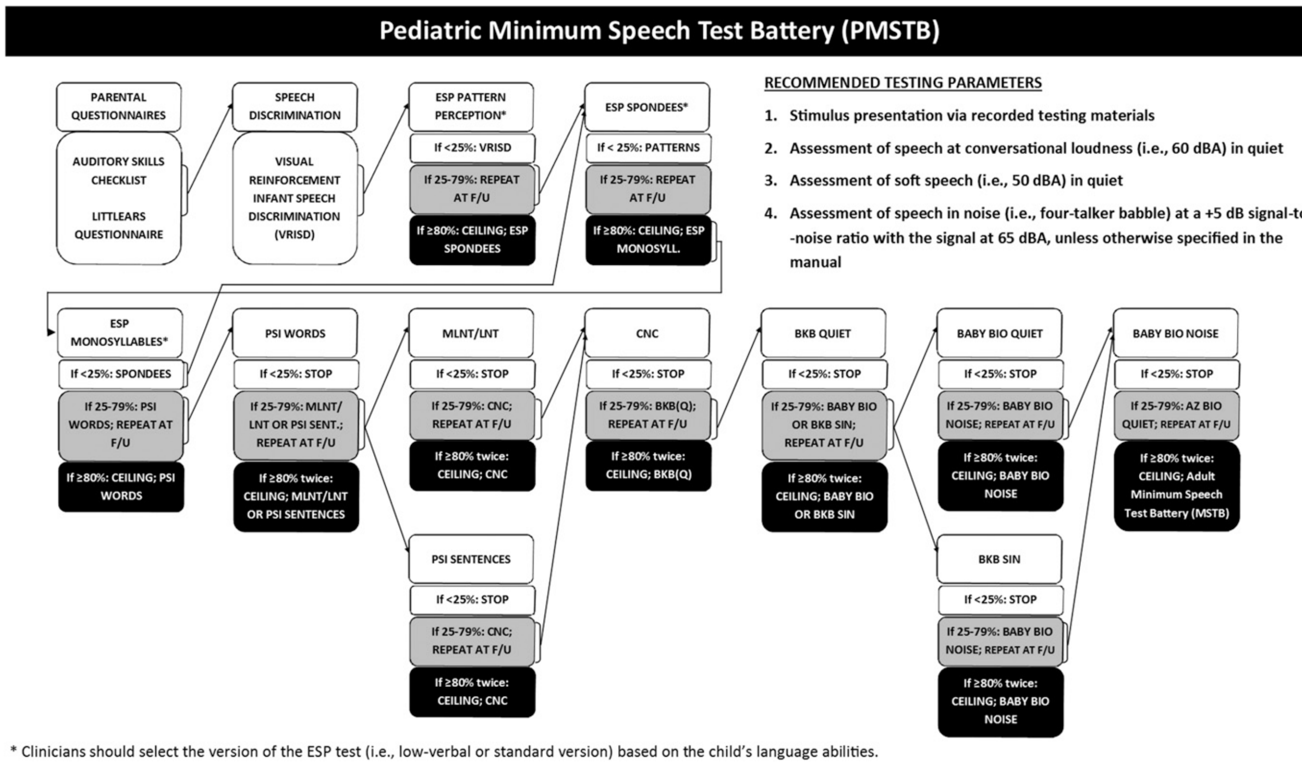
APPENDIX A



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)