CHAPTER NINETEEN

Understanding Communication Outcomes: New Tools and Insights

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Recent advances in newborn hearing screening (NHS) and amplification technologies are expected to positively impact the outcomes of children with hearing loss (HL). However, more research is needed to determine if anticipated changes have been realized. Questions related to children with mild to severe hearing loss represent a priority research agenda. Three decades ago, Dr. Julia Davis described this group as "Our Forgotten Children" and noted a tendency for professionals to underestimate their educational needs (Davis 1990). Today gaps in research remain, and evidence to guide clinical and educational practice is lacking.

One of the challenges in conducting outcomes research includes limitations in assessment batteries, particularly in the younger ages. The monitoring of young children's achievement of vocal and early verbal landmarks may provide insights about the effectiveness of interventions, including amplification strategies. There is a need for tools that are sensitive to developmental changes in the early stages of language development. In addition, children with hearing loss may be at particular risk for delays in areas that are dependent on audibility (i.e., grammatical endings that are marked with fricatives). Assessment strategies that probe developmentally vulnerable aspects of spoken language are needed. The purpose of this article is to describe the rationale and structure of three measurement tools that are designed to address these assessment gaps. The motivation for use of these measures arose during the implementation of a multi-site prospective, longitudinal study of the outcomes of children with mild to severe hearing loss. Following some background about the longitudinal study, the three measurement tools and related preliminary data are described.

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Longitudinal Study Background

A collaborative team of researchers from the University of Iowa, Boys Town National Research Hospital (BTNRH) and the University of North Carolina-Chapel Hill are involved in a five-year study called Outcomes of Children with Hearing Loss (OCHL), funded by the National Institute on Deafness and Other Communication Disorders (NIDCD). This project emerged from recognition of the need for a study of the outcomes of a focused group of children who are hard of hearing. Relative to studies of deaf children, the literature on children with mild to severe hearing loss is fairly sparse. Reviews of the extant literature on children who are hard of hearing (Moeller, Tomblin, Yoshinaga-Itano, Connor and Jerger 2007) revealed concerns with sample composition, measurement strategies and sample representativeness. Some studies include both deaf and hard of hearing children in their samples, making it difficult to draw conclusions about those children with lesser degrees of hearing loss. Studies that focus on samples of children with mild to severe hearing loss tend to have small samples sizes, which also limit opportunities for generalization. No previous studies in the US have attempted a population-based sample. Additionally, most previous studies provide limited information about the children's amplification and/or status of aided audibility. This is concerning given that these factors are likely to explain some variance in outcomes. Finally, previous-generation studies include children with dated amplification technologies and lack of access to NHS. This lim-

its the degree to which past literature is representative of the current generation of children with hearing loss. It is clear that there is a need for an epidemiological approach to the study of this group of children.

The OCHL project is designed to address three primary aims. The first aim is to describe the background characteristics of the children and their families and to detail the extent and nature of the children's intervention services. In addition, factors that are associated with variations in service delivery or receipt are explored. In the second aim, the team is measuring a broad range of child and family outcomes. Child outcomes are considered for a variety of domains, including speech perception, speech and language, behavior and academic and psychosocial skills. Family outcomes include perceived benefits from interventions and ease of access to systems of support. In order to interpret various outcomes, the children with hearing loss are being compared to a cohort of children with normal hearing (NH), who are matched on age and socioeconomic status (SES). The final project aim is to understand how key variables, including child, family and intervention factors, combine to influence outcomes. Multivariate statistical models and path analyses (structural equation modeling) are employed to address this aim.

The study employs an accelerated longitudinal design, which is depicted in figure 1. This design was necessary, given the interest in understanding a wide range of developmental outcomes, from infant vocalization to academics and psychosocial skills, within the confines of a five-year study. In this design, children in the age range 6 months to 6 years, 11 months enter the study, filling slots along a broad age continuum. Once a child enters, prospective data are collected for three consecutive years (dark lines in figure 1). In addition, selected retrospective records (dotted lines, figure 1) are gathered to the degree possible. So, if a child enters at 3 years of age, testing is completed annually at ages 3, 4 and 5 years. Similarly, a child entering at 5 years is seen at ages 5, 6 and 7 years. Children are purposely scheduled around their birthdays, allowing the team to analyze cross sectional results for each annual assessment period. The testing schedule is modified for infants, who are seen at ages 6, 12, 18 and 24 months before moving to the annual test intervals. The research team was interested in capturing toddler's transitions from pre-lexical to early lexical stages, necessitating closer monitoring than with older children.

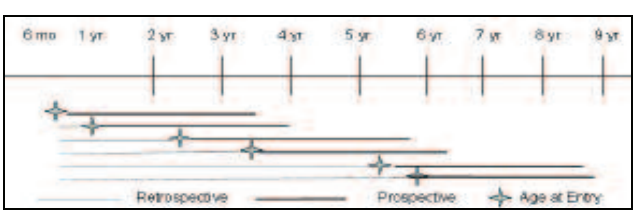

Figure 1. Schematic representation of the accelerated longitudinal design.

The OCHL study currently is in the third year of the five-year funding cycle. The project goal is to recruit 400 children with mild to severe hearing loss (HL) into the study. After one year of recruiting, we are following 232 children and recruiting efforts continue. Selection criteria include: 1) better ear pure tone averages (BEPTA) of 25-75 dB HL (at 500, 1k, 2k and 4khz); 2) permanent, bilateral hearing loss; 3) a primary caregiver using spoken English in the home; and 4) no major secondary disabilities that would preclude participation in the test battery. To date, the mean better ear pure tone averages for children with HL are similar across the three collaborating sites (47.6 dB HL for both Iowa and BTNRH and 52.2 dB HL for North Carolina). Approximately 67% of the children had their hearing losses identified through newborn hearing screening. To date, the team has enrolled 64 children with normal hearing (NH) in the comparison group. These children are matched on age and socioeconomic status to children with hearing loss. The plan is to enroll 150 children in the NH group.

A comprehensive review of the literature on hard-of-hearing children reveals variable conclusions about the longer term impact of mild to moderately-severe hearing loss on spoken language (Moeller et al. 2007). Selected studies report that some children perform like age-matched peers with NH by the early elementary years (Borg, Edquist, Reinholdson, Risberg and McAllister 2007; Gilbertson and Kamhi 1995; Moeller, McCleary at al. 2010; Norbury, Bishop and Briscoe 2001). Others observe persistent speech and language delays (Davis, Elfenbein, Schum and Bentler 1986; Delage and Tuller 2007; Elfenbein, Hardin-Jones and Davis 1994; McGuckian and Henry 2007; Wake, Hughes, Poulakis, Collins and Rickards 2004), often specifically in phonology, speech intelligibility and morphosyntax. This has led some to suggest that these may represent vulnerable areas of development for children with hearing loss (Delage and Tuller 2007; Moeller, McCleary et al. 2010). Predicting that phonology and morphology may be affected by the presence of mild to severe hearing loss, the team sought to develop and identify new tools that would support exploration of these skills at earlier ages or in greater depth than traditional protocols allow.

Three assessment tools for young children will be described in the sections that follow. They include the: 1) Vocal Development Landmarks Interview (Moeller and Bass-Ringdahl 2010); 2) Open and Closed Set Test (Ertmer, Miller and Quesenberry 2004); and 3) Morphological Elicitation Procedure (Moeller, Spratford, Berry and Tomblin 2010). The first two measures are designed to assess early vocal and phonological skills in infants and "2 year olds". The Vocal Development Landmarks Interview was designed for use in the OCHL project, and the Open and Closed Set Test was developed at Purdue University by David J. Ertmer and colleagues. The third tool, which was also created for the OCHL Project, assesses development of morphology.

Vocal Development Landmarks

To set the stage for a description of the Vocal Development Landmarks Interview, it is useful to review steps in typical development. Selected stages are illustrated in table 1, and they provide general guidelines for landmarks that audiologists and others may observe as children develop their perceptual-motor skills underlying speech. Young infants are described as being in an expansion stage of vocal development between 3 and 8 months of age (Nathani, Ertmer and Stark 2006). The expansion stage is characterized by limited oral-motor control, so typically vocalizations do not sound "speech like." In gross motor development, infants progress from crawling to walking, and early movements have limited control. They become more refined over time. So it is with the progression from vocalization to verbalizations during the first two years of life; as perceptual motor-skills become more refined, behaviors become progressively more "speech like." Early vocalizations are often the result of infants' explorations. For example, growls are produced as the infant explores the back of the throat. Similarly, as infants explore the airstream mechanisms, they commonly produce sounds on inhalation, called ingressives (Oller, Eilers, Bull and Carney 1985). Exploration of various parameters of the vocal tract may result in the production of high pitched squeals that may vary in intensity (Ertmer and Iyer 2010). Sounds that are more akin to speech emerge as infants produce early vowels that may be recognized as adult-like (Ertmer and Iyer 2010). Children also begin to engage in the production of consonant-vowel syllables; however they typically produce *marginal* syllables at this stage. These have been described by Oller (2000) as primitive combinations of consonant-like and vowel-like forms. In marginal babble, the timing of the transition between consonants and vowels is much slower than typically produced in adult speech (often over 120 ms; Ertmer and Iyer 2010). When these forms are produced, they sound uncoordinated (motor control is still emerging), and they do not sound like they would fit neatly into a real word. An illustration is a child who produces a sequence like /mmmbwa/. This form would not fit into an English word, and it sounds as if the child is still learning to put sounds together. If parents report that a child has started to babble, it is important to determine if these are marginal babbles or true canonical forms.

Following the expansion stage, young children progress to the basic canonical stage, which typically occurs between 5 and 10 months of age in children with NH. (Oller provided a technical definition of canonical syllables, based on acoustic properties of the vocalization. See Oller 2000 for a review.) For the audiologist or other speech/hearing professional, it may be valuable to consider the following questions: "Does this syllable or this set of repeated syllables sound 'speech like' in timing? Could this syllable fit into an English word?" "Is the syllable [bo] produced in a well-timed, efficient manner? Does it sound like it would fit into the word boat?" The onset of true canonical syllables has been shown to be delayed in children with hearing loss (Oller and Eilers 1988), although selected children with moderate-to-severe hearing loss have been shown to babble within a time frame that is typical for infants with NH (Nathani, Oller and Neal 2007). It is important to monitor children for the onset of canonical syllables, as this may reflect maturation in auditory-based perceptual-motor skills. At this basic canonical stage, infants may produce both reduplicated [bababa] and variegated [bidoda] strings (Ertmer and Iyer 2010). They may also continue to explore the vocal tract with variations in pitch and intensity (from squeals to whispers).

At the next stage, advanced forms emerge. Ertmer and Iyer (2010) describe this stage of advanced forms as the highest level of prelinguistic vocal development, which is reached sometime between 9 and 18 months of age. This stage is characterized by phonetically complex combinations, such as those that end with a consonant (cvc like [bot] or a vc like [an][1]), or use diphthongs /aI/ or/au/). The child may also produce complicated strings of variegated sequences that are inflected in a way that

[1] cvc means consonant-vowel-consonant combination; vc means vowel-consonant combination.

sounds like talking (i.e., jargon). In general, the child's productions are becoming more word like. It is expected that the single word stage of development includes a mix of prelinguistic vocalizations and words (Robb, Bauer and Tyler 1994).

Measuring Vocal Development Landmarks through Parent Report

Some investigators use parent report as a method for identifying changes in vocal development in infants and toddlers. Parent report is widely used as a tool in characterizing changes in early vocabulary development (Dale and Fenson 1996) and parent report has been shown to yield valid estimates of vocabulary size for children in various groups, including those with NH (Dale 1991) and those with HL (Thal, DesJardin and Eisenberg 2007). Furthermore, parent report was found to be a reliable method for assessing canonical babble onset in young infants (Oller, Eilers, Neal and Schwartz 1999). More recently, a comprehensive parent-report scale entitled the *Production Infant Scale Evaluation Questionnaire* (PRISE) was developed in Israel (Kishon-Rabin, Taitelbaum-Swead, Ezrati-Vinacour, Kronenberg and Hildesheimer 2004; Kishon-Rabin, Taitlebaum-Swead and Segal 2009). These authors reasoned that the evaluation of preverbal behaviors would be a reflection of functional hearing in infancy, especially useful for infants with HL aged 6-12 months. The scale was designed to assess the major milestones in preverbal vocal development. The PRISE was validated in a study involving 260 infants with normal hearing, and results demonstrated changes in vocal behaviors as a function of age (Kishon-Rabin et al. 2009). Studies also document that the PRISE is sensitive to varying degrees of HL in young children (Kishon-Rabin et al. 2009). These authors have documented the relevance and practicality of a tool that indirectly monitors auditory development through parent report about children's achievement of vocal landmarks. Authors in Australia recently adapted the PRISE to create a criterion referenced parent report scale entitled the *Infant Monitor of Vocal Production* (IMP; Cantle-Moore 2008). The goal of the IMP is to record the emergence of auditory-facilitated changes in prelinguistic vocal development as infants receive hearing aids and cochlear implants. Both of these measures have considerable merit and are likely to yield information to guide early intervention practices.

An apparent limitation of these tools, however, is the need to describe vocal landmarks using words. This concern came about when examining the form of some of the questions used to probe parents' observations of their children's vocal behaviors. One question on the PRISE, for example, asks, "Does the infant produce dif-

Expansion Stage (precanonical) 3-8 months	Basic Canonical Stage 5-10 months	Advanced Forms 9-18 months
• Vowels • Growls • Ingressives • High Pitch Squeals • Marginal babble	• CV syllable-speech like • Reduplicated babble [bababa] • Variegated sequences [badido] • Squeals • Ingressives • Whispers	• Child advances to forms beyond simple consonant-vowel, such as vowel + consonant (up, eem), CVC (mom, tut), CCVC (stop!) • Diphthongs (ow) • Complex variegated babble • Jargon

Table 1. Selected early stages of vocal and verbal development, taken from the Stark Assessment of Early Vocal Development-Revised or SAEVD-R (see Ertmer and Iyer 2010 ; Nathani, Ertmer and Stark 2006 for a more complete description). The three stages presented here are preceded by a Reflexive Vocalization Stage (birth to 2 months) and a Control of Phonation Stage (1 to 4 months).

Interview Section	Skills Probed	Item Format
Warm Up	Precanonical vs. canonical stage	Open ended question: "What sounds does your little one make on a typical day?"
	Age at first canonical syllables	If the parents indicate that the child is producing true syllables, they are asked to recall when they first heard these forms (audio file examples provided).
	Age at first reduplicated syllables	
Precanonical Stage	Presentation of vocal behaviors that have been observed to be atypical in some children with hearing loss. These items screen for typical vs. atypical vocal behaviors in children > 12 months of age.	Listen to audio files of: a) Pitch breaks/atypical high pitch b) Creaky or harsh vocal quality c) Use of glottal sequences d) Ingressive vs. egressive vocalizations (paired comparison)
	Beginning levels of vocal imitation	Parent hears samples of 4 infants imitating vocalizations or onomatopoeia sounds (meow)
	Production of a range of vowel-like sounds	Three audio files of vowels are played and parent is engaged in a discussion of the vowel types they typically hear the child produce.
Canonical Stage	True consonant-vowel syllables vs. vowels	Paired comparison
	True consonant-vowel syllables vs. glide-vowel sequences	Paired comparison
	Well timed consonant-vowel syllable vs. marginal syllables	Paired comparison
	Reduplicated canonical sequences "bababa" vs. single CV syllables only "ba"	Paired comparison
	Variegated sequences "bagude" vs. reduplicated sequences "bababa"	Paired comparison
	Complex variegated with intonation (jargon) vs. reduplicated sequences	Paired comparison
Word Stage	Word imitation	Audio files are provided with examples that are "far off," "getting closer" or "very close" to the model. Parent judges how close the child is to the model.
	Proto-word production	Play audio examples and ask parents to share child examples.
	Understandable words	Play examples; ask parent to list.
	Understandable word combinations	Play examples; ask parent to list.

Table 2. Description of content contained in the Vocal Development Landmarks Interview.

ferent consonant-vowel combinations? For example, when the infant plays with toys or addresses family members, does he produce parts of words, such as ba, du or pi, etc.?" This shows obvious effort to avoid complex terms (like canonical syllable), and to make the targets clear for families. However, it still involves the use of terms and expressions that could lack clarity for parents. In addition, some distinctions related to vocal control (e.g., pitch breaks, ingressives) or syllable structure (e.g., marginal versus canonical syllables or glides + vowels versus canonical sequences) can be quite challenging to mimic accurately or to describe verbally. The *Vocal Development Landmarks Interview* was developed by Moeller and Bass-Ringdahl (2010) to address this perceived limitation of existing tools. Both researchers have conducted longitudinal studies that included systematic collection of vocal recordings from young infants with HL and NH. Sound files that were clear examples of the target vocal landmarks were identified from these archival recordings. They were then embedded into a presentation such that each question on the interview could be paired with vocal samples for the parents to hear. This allows the examiner to support parental understanding of the vocal behaviors of interest and ensure that the parent and examiner are "on the same page" about the behavior being discussed. In many cases, paired comparisons are provided to make distinctive landmarks clear without the need to verbally describe them (e.g., ingressive versus egressive vocalizations and marginal versus true canonical syllables).

The Vocal Development Landmarks Interview is designed to be appropriate for a developmental period from about 6 months to 24 months. It includes four primary sections with the following areas of focus: 1) warm up (open ended questions), 2) precanonical vocalizations, 3) canonical syllables, and 4) word productions. Details regarding the specific skills probed and various task formats are included in table 2. The warm up questions were suggested to the OCHL team by Dr. Kim Oller. These questions are open-ended in nature and help to determine up front if the child is at a precanonical or canonical stage. The precanonical section of the interview explores a number of vocal behaviors that have been observed to be delayed in some children with hearing loss (e.g., protracted use of glottal sequences and protracted use of harsh quality or ingressive breath stream). In addition, this section includes items related to early vocal imitation, vowel repertoire, and glide-vowel sequences. The canonical syllable section uses paired comparisons to identify landmarks such as: 1) true syllable productions (not marginal), 2) reduplicated babble sequences, 3) variegated sequences, and 4) jargon. The word production section includes a rating of word imitation accuracy, and questions related to the child's use of words identifiable only in the family and words or word combinations understood by others.

The interview response formats include: 1) answering open-ended questions, 2) listening to target samples and indicating whether or not the child exhibits the behavior, 3) listening to paired comparisons and determining which behavior is most characteristic of the child, and 4) listening to samples of word imitations and indicating on a visual scale how close the child's imitations are to words the family models. Figure 2 shows an example of the paired comparison paradigm. This item is designed to probe whether the child is producing marginal or true syllables. The parent is asked, "On a typical day, does your child sound more like the children in the top row or the bottom row?" Top row samples are clear canonical syllables ([ba], [du], [ga]), while those on the bottom row are marginal productions with slow transitions between the consonant and vowel. Parents may respond that their child's vocalizations are more like the top or bottom row, or a combination of both types. Then parents are asked to judge the relative frequency of each type of vocalization on a scale including the terms *never, rarely, sometimes and often.* Weighted scores are as-

Figure 2. Example of a power point slide from the Vocal Development Landmarks Interview. This item is set up in a paired-comparison paradigm. The audio files contrast true canonical syllables with marginal syllables.

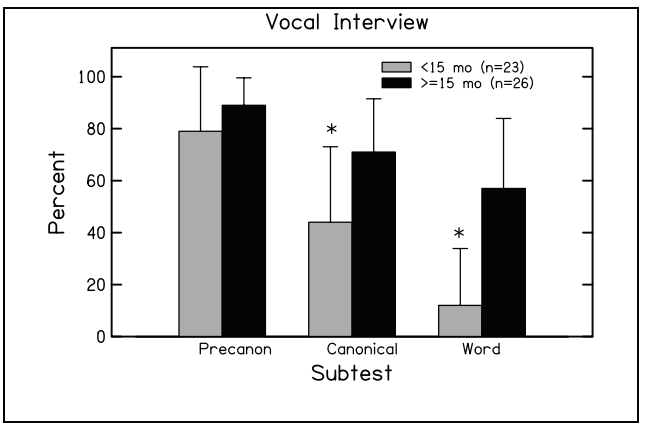

Figure 3. Results of preliminary analysis of the Infant Vocal Development Landmarks Interview. The average percentage of points accrued for younger (<15 months) versus older (> 15 months) infants shown for the precanonical, canonical and word level categories. Asterisks show significant differences between age groups; bars represent the standard deviations.

signed on each item to reflect presence and/or the relative frequency of the target vocal landmarks in each section. In the figure 2 example, the parent might respond that the child produces sounds more like the children in "the bottom row," and then reports that these (marginal syllables) are heard *sometimes*. The examiner then asks the parent to comment on how often the child produces sounds like those in the top row (canonical syllables), and the parent indicates that sounds like those are *rare*. This pattern of results receives credit at the precanonical, but not the canonical level. The response suggests that the child is not yet at the canonical stage, but syllables may be emerging, and parents can be guided to listen for those vocal behaviors.

The OCHL team has observed several advantages to this interview approach. Provision of the audio files has supported the goal of avoiding terminology that is unfamiliar to parents. The vocal samples also ensure that parents and examiners are talking about the same behaviors. Finally, provision of vocal samples has helped to calibrate across multiple examiners, ensuring that the same behaviors are probed and that examples provided to parents are standardized.

To date, responses to the Vocal Development Landmarks Interview have been analyzed for 49 families of children with HL. These preliminary data are shown in Figure 3. Results are plotted as percentage of items receiving credit by younger infants (n = 23; Mean age = 11 months, SD = 2.32 months) compared to older infants (n = 26, Mean age = 18.7 months, SD = 1.29 months) for precanonical, canonical and word categories. At these ages, both groups of children had achieved most of the precanonical vocal behaviors that were surveyed, and no significant differences were found as a function of age ($t\ [47] = 1.84$, $p = .072$). This suggests that appropriate precanonical vocal behaviors were observed in this group by 11 months of age. Both canonical ($t\ [47] = 3.77$, $p = .001$) and word forms ($t\ [47] = 6.58$, $p = .001$) increased significantly with age. These early results suggest that the interview is reflecting the expected developmental patterns.

The OCHL team is currently initiating a validation study with a group of infants with NH and HL, aged 6 to 24 months. In this study, parents will complete the Vocal Development Landmarks Interview and will then provide a vocal sample of the child from the home setting within one week of the interview. The recordings are collected using a digital language processor (DLP) called LENA (**L**anguage **EN**vironment **A**nalysis). This device uses a microprocessor with advanced compression and audio components that are based on hearing aid technologies. The parents are provided the DLP through the mail. After receiving the device, they turn on the DLP and place it in a small vest worn on the child's chest. Illustrations of the DLP and child vest are shown in Figure 4. The DLP is capable of recording 16 continuous hours of talk in home/community environments. Parents who have consented to use of the LENA complete the recording and return the recorder to the research center through the mail. The recording is then downloaded, and the software automatically tags and segments the audio data, providing the research team with various reports. One of those automated reports shows the number of child vocalizations that occur throughout the day in 5-minute interval segments. This makes it straightforward to identify highly vocal periods throughout the day. After locating a period of high vocal activity, the researcher is able to click on the data bar and listen to the actual vocal sample

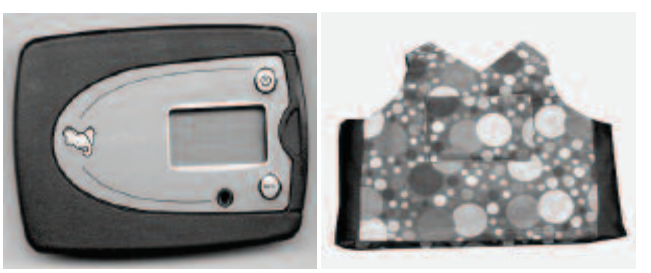

Figure 4. Language Environment Analysis (LENA) equipment. The picture on the left is of the digital language processor (DLP). The picture on the right shows the vest that holds the DLP on the child for full day recordings. More information may be accessed at www.lenafoundation.org.

represented by that time block. Using this technology, the team will identify 10 separate one-minute periods of vocal activity from different time periods throughout the child's day. This is designed to garner a representative sample of vocalizations and reduce the effects of specific contexts/activities on the child's vocal behavior. Three blinded judges will listen to the identified samples to verify the presence of the behaviors surveyed on the Infant Vocal Development Landmarks Interview. Their ratings will then be compared to the parent report and level of agreement will be determined. Pilot data on three children with HL suggest that this may be a feasible approach to validation of the instrument. Comprehensive information on automated analysis using LENA is available at www.lenafoundation.org.

A Measure of Perception-Production in Young Children

The second measure to be described, the *Open and Closed Set Test* (O&C; Ertmer et al. 2004) was created to assess children's auditory-based skills during the first word stage of language development. The test is presented in a face-to-face auditory-visual condition (although it could be adapted for presentation in an audiological test suite), and was designed to be developmentally appropriate for children at the single word stage. It consists of three separate ten-word lists. The lists include words that are present in the vocabularies of 75% of typically developing 2-year-olds (Dale and Fenson 1996). These items are represented in the stimulus manual with realistic photographs. The O&C task has two main components for each stimulus word. The first is an open-set task, where an adult (mother or examiner) produces a word and the child is asked to repeat it. The examiner records the child's production, which is scored later for accuracy of phonemes and syllables. In the second task, the child is asked to identify the target word from a closed set of three photographs. To illustrate the procedure: 1) a child is asked to say, "keys," 2) the child imitates, 3) the examiner reveals a set of three photographs, and the adult says, "Now find it." The child receives two points for identifying the correct object without further prompting. If the child does not respond on the first trial, a second trial is given, but one point is deducted from the word identification score.

Stimulus Word (# phonemes)	Transcribed response (#phonemes matched*) *Ignore consonant voicing errors	Criteria for matching target: • 2 consonants or vowels AND • Correct syllable number Matches criteria: Yes/No	Picture selected (1, 2, 3) • 2 pts = correct ID without repetition • 1 pt = correct ID following a repetition
Baby (4) [bebi]	[be i] (3 /4)	YES	**√1** 2 3 Rep? √Y/N Pts: **2**
Keys (3) [kiz]	[tis] (2 /3)	YES	**√1** 2 3 Rep? √Y/N Pts: **2**
Cow (2) [kau]	[bo:] (0 /2)	NO	1 √2 **3** Rep? Y/√N Pts: **0**
(Total 36 phonemes)	% phonemes matched: (/36 X 100 = %)	% acceptable words: (/10 X 100 = %)	Total number of points:

Table 3. Scoring of selected items from the O & C Test (Ertmer et al. 2004). Columns 2, 3 and 4 yield scores for phonological accuracy, word acceptability, and word identification respectively. Note: underlined forms in the third column represent the targeted correct answer.

Three measures are yielded from this test. The first score rates phonological accuracy, reflecting the degree to which the child's imitation matches the adult target form. This is derived from an on-line phonetic transcription of the child's production, which is then compared to the target. As seen in the scoring example in Table 3, a child who produces [be i] for [bebi] (baby) would be credited with three out of four phonemes correct. The second score is for word acceptability, which awards one point for each word that meets the following criterion: at least two phonemes (vowels or consonants, ignoring voicing errors) match the target phonemes AND the number of syllables is correct. The "baby" example in the table meets these criteria, and so the child receives one point for word acceptability. This score is less stringent than the phonemes-matched score, but may reflect the degree to which the word could be recognized in spite of errors (i.e., speech intelligibility). The final score credits the child with appropriate identification of the target spoken words. In other words, it assesses the child's understanding of basic spoken vocabulary words.

The OCHL team has found that this measure is appropriate for children as young as 18 months, and has been especially useful with 2-year-olds. Figure 5 illustrates preliminary results comparing the performance of eight children with NH to 32 children with HL, all tested between 26 and 29 months of age. Results of Levene's test indicated that the variances for the groups were significantly different for all three subtests. Therefore, the nonparametric Mann Whitney U test was used to compare group means. For phonological accuracy, the children with NH averaged scores of 84.02 percent, while the children with HL scored on average at 59.28 percent, and this difference was significant ($p = .005$). Word acceptability scores were also significantly different ($p = .012$), with percent correct scores of 92.5 and 66.2 for the NH and HL groups respec-

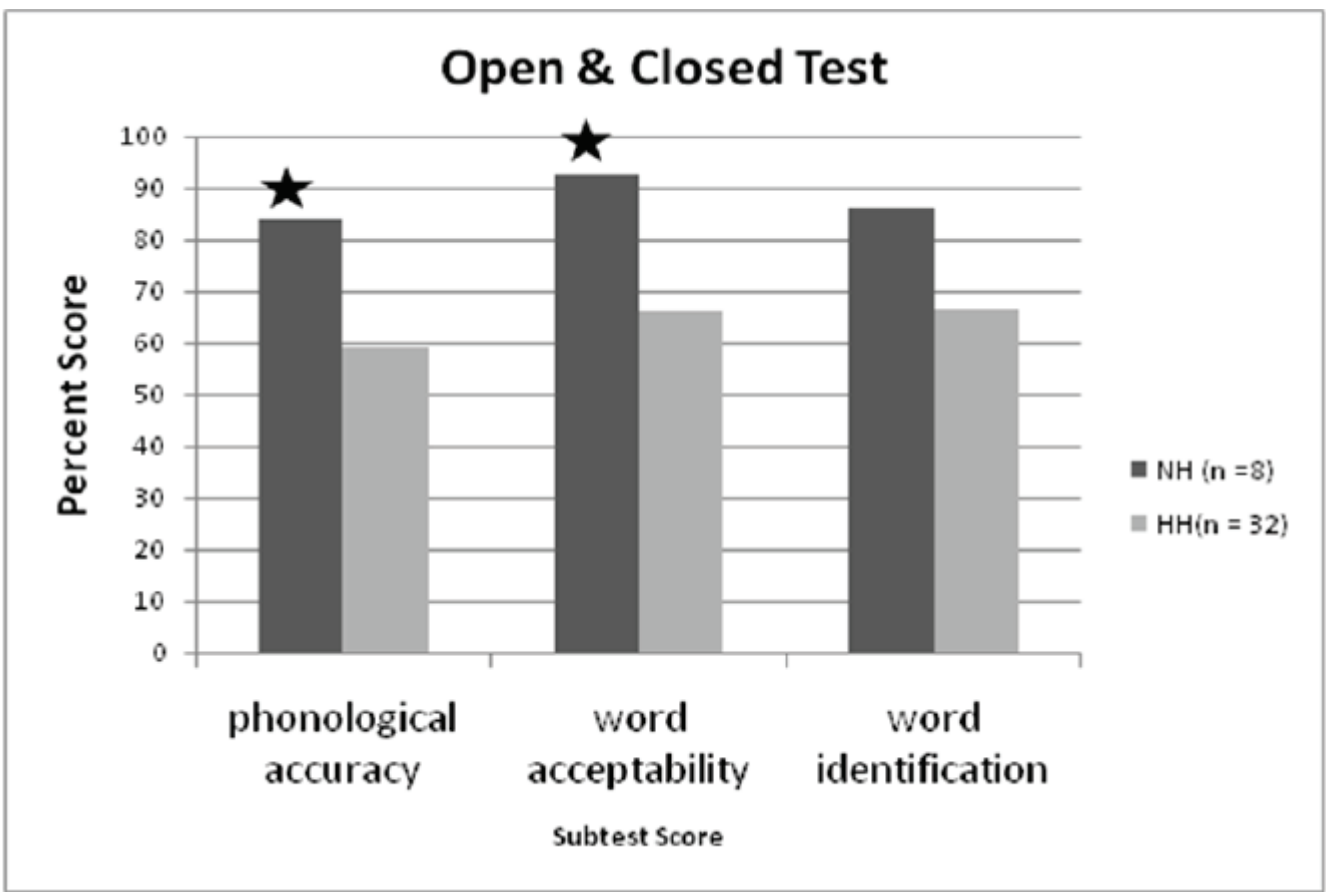

Figure 5. Preliminary results from the Open and Closed Set Test (Ertmer et al. 2004) on eight children with NH compared to 32 children with hearing loss, all of whom were 2 years of age. Stars indicate significant between group differences.

tively. The groups did not differ significantly on the word identification measure (NH = 86.2; HL = 66.4; p = .198), although the average score of the children with NH was higher than that of the children with HL. The OCHL team is currently enrolling more children in the NH group, which will allow for more meaningful comparisons. However, initial results suggest that this measure is sensitive to differences between children with NH and HL in the area of speech production. It also has been helpful to compare perception and production on the same items.

Morphology Elicitation Measure

The final measure is a set of elicitation procedures that were designed to probe children's development of grammatical morphology. Recent studies indicate that preschool-aged children with mild to severe hearing loss are at risk for delays in morphosyntax McGuckian and Henry 2007; Moeller, McCleary et al. 2010), although not to the extent observed in children with Specific Language Impairment (Norbury et al. 2001).

Several factors may influence the development of grammatical morphology in children with hearing loss. Perhaps the most familiar and well documented involves limitations in the audibility of high frequency phonemes, due to the restricted bandwidth of many hearing aids (Stelmachowicz, Pittman, Hoover and Lewis 2001, 2002). Although nonlinear frequency compression techniques are increasingly being used (Glista et al. 2009), issues pertaining to effects of noise, distance and reverberation continue to present challenges to audibility. Song, Sundara and Demuth (2009) described grammatical properties that could influence the perceptibility of morphological endings. They noted that the third person singular ending (he want**s**) typically occurs in the middle of sentences, due to the typical position of main verbs in English. In contrast, plural endings on nouns (two **cat**s) regularly occur at the end of phrases. Sentence medial endings may be produced with less amplitude than those that occur on words that complete phrases. Another issue raised in the literature is the effect of input frequency on the child's mastery of certain morphological forms. McGuckian and Henry (2007) suggested that third person singular may be more challenging for children with hearing loss because it occurs less often in language input than other forms. The combined effects of less exposure in the input and reduced amplitude due to sentence position could result in making the third person singular form particularly challenging for children with hearing loss (Moeller, McCleary et al. 2010). This hypothesis is currently being explored in the OCHL project.

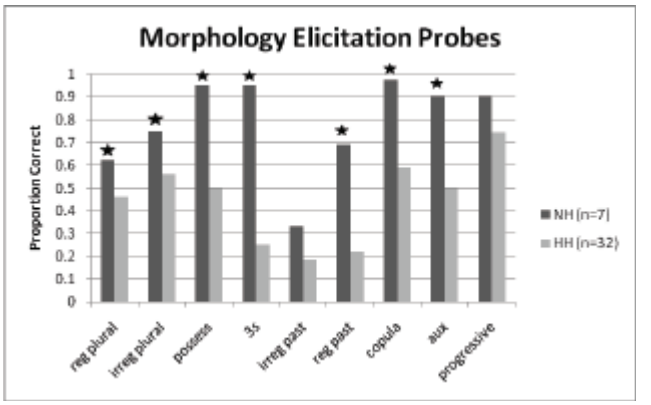

Figure 6. Preliminary results from the grammatical morphology elicitation probes. Bars show the proportion of items correct for children with NH compared to those with HL. Stars indicate significant differences between groups ($p < .01$). Reg plural = regular forms of plural nouns (cat/cats), irreg plural = irregular forms of plural nouns (foot/feet), possess = nouns marked for possession (Mary'**s**), 3s = third person singular ending on verbs (Joe walk**s**), irreg past = irregular past tense verbs (run/ran), reg past = regular past tense verbs (walk, walk**ed**), copula = be verb forms (He **is** funny), auxiliary = (for this measure) is/are used as a helping verb (he is running), progressive = present progressive form of the verb (they are play**ing**).

Progress in phonological development also can be expected to influence children's ability to produce morphemes in certain contexts. Song and colleagues (2009) discussed the contribution of phonological complexity to children's consistency in the use of morphological endings. A child with hearing loss, for example, might be able to add the /z/ ending to a word like "bows" (/boz/), where the fricative follows a vowel. However, they might not be able to in a word like "birds," where adding the +s morpheme requires production of a triplicate blend [rdz]. It is important to recognize that limited audibility for high frequencies could also affect phonological development and ability to produce complex forms could be delayed.

Given the evidence that grammatical morphology may represent a vulnerable aspect of language development in children with HL, the goal of the OCHL team was to create a set of tasks that would sample various morphological endings. Additionally, because children with HL may have more difficulty producing morphological endings in some words than others, the OCHL team determined that these tasks must sample each

[1] Due to unequal variances, nonparametric tests (Mann Whitney U) were run in all cases except past tense and progressive where variances were equal (and t test results could be used).

morphological ending multiple times. Many omnibus tests of language development include some items that probe grammatical morphology. However, they typically are limited in number of items and the scope of forms included. The morphological elicitation procedure developed for OCHL probes nine different forms, three involving noun markers and six involving verb tense and agreement markers. Six tokens are elicited for each form type. Comprehensive details about this measure are contained in Appendix A. The procedure begins with a phonological task, followed by probes of the nine grammatical morpheme types. The initial phonological task is presented in the form of a lotto game, and is designed to ensure that the child is able to produce final consonants (/s/, /z/, /t/, /d/) in non-morphemic contexts (e.g., *bus, read, hat*). These data are helpful in determining the degree to which speech production errors may be affecting the child's performance on production of grammatical morphemes. Scores on the phonological measure affect which items are administered and how items are interpreted. For example, if a child is unable to produce /s/ and /z/ and always omits these ending sounds, morphology subtests involving those phonemes are not administered. In contrast, if a child correctly produces /s/ in simple words on the phonological task, but always omits them in the plural or third person singular tasks, the errors are likely to be morphological.

The probes themselves are presented in the context of different movie scenarios, presented on DVD. The movie vignettes were created to be engaging and relevant for young children and to allow for rapid elicitation of the target forms. For forms like singular-plural nouns, participants see child actors opening birthday gifts, presents or a treasure box and pulling out single or multiple objects. The child is asked, "What did he/she find?" The DVD format has particular advantages for eliciting past tense forms, which are hard to represent in static pictures. For an irregular verb like "blew," for example, participants see children blowing bubbles and then the action ends. Children are asked, "What did the girls do?" This elicits the form, "blew bubbles." Possessive forms (e.g., mommy's sweater) are presented in the context of a family folding and putting away laundry. For the third person singular verb form, a procedure was adapted from Rice and Wexler (2001). The DVD shows photos of people in various roles (e.g., swimmer, dancer) and participants are asked to comment on what the person does every day (e.g., Everyday she… swims or dances). Remaining examples are described in Appendix A.

Preliminary results from the OCHL project are presented in figure 6. The proportion of items correct for each target morpheme is shown for 4 year-old children with NH (n = 7) and HL (n = 32). In general, the children with HL were less accurate than age-matched peers with NH in productive morphology for verbs and nouns. Significant[1] between-group differences were found for the following verb endings: 1) third person singular (he wal*ks*, $p < .001$), 2) regular past tense (she walk*ed* $p = .003$), and 3) *be* verbs used as a copula (he *is* big or he'*s* big, $p = .004$) or auxiliary (she *is* walking or she'*s* walking, $p = .013$). Notably, the largest between-group differences were observed for the third person singular verb form, which fits with the prediction that these may be particularly challenging for children with HL. Significant differences also were observed for noun endings, including: 1) regular plural (cat/cats, $p = .028$), 2) irregular plural (foot/feet, $p = .043$) and 3) possession (mommy's coat, $p = .014$). No differences were observed for irregular past (go/went), where, as expected, both groups demonstrated low accuracy at this age, and for progressive (+ing on verb), where both groups achieved greater than 75% accuracy.

Audibility was calculated using the Speech Intelligibility Index (SII) for a subgroup of 18 children for whom both SII and morphology scores were available. For this subgroup of children, significant positive correlations were found between SII and performance on third person singular ($r = .494$, $p = .037$), regular plural ($r = .661$, $p = .003$), and possessive ($r = .470$, $p = .049$). Each of these rules involves production of fricatives. Forms that may be considered to be more audible contrasts (e.g., foot/feet; go/went) did not show this association with SII. Interestingly, only the auxiliary verb subtest was significantly and negatively correlated with better ear pure tone average (PTA; $r = -.473$, $p = .01$), but not the other subtests. These results suggest that the SII measure may be more sensitive than PTA to the skills measured on this task. These data are considered to be preliminary, and are limited by the small sample size in the normal hearing group and the need for further validation of the morphology instrument. However, they show interesting trends that will be pursued in future work. In addition, the OCHL team is collaborating with Dr. Amanda Owen at the University of Iowa to compare findings on this measure to spontaneous language sample data on the same children. In general, the use of focused elicitation probes to study the development of grammatical morphology in children with hearing loss appears to have merit.

Summary

There is a need to carefully examine the outcomes of a new generation of children with mild to severe hearing loss, who have access to early identification and advancing hearing technologies. Outcomes research can provide information about the effectiveness of technological innovations and direction for interventions. The importance of developing additional sensitive measurement tools has been promoted in this article. It has been suggested that there are two pressing needs: 1) development of measures that are appropriate for children under 2 years of age, and 2) a focus on aspects of speech and language that may be at particular risk in children with permanent hearing loss. Phonological development and grammatical morphology represent vulnerable aspects of development for this population, which means that it is important to devote attention to these areas in assessment and intervention.

To address these goals, three tools have been implemented in the OCHL project. The Vocal Development Landmarks Interview was created to monitor children's progress from prelexical vocal productions to early real word use. Parents listen to samples of the target vocal behaviors during the interview. The audio files support the accuracy of parent report. Results to date suggest that the interview procedure is sensitive to developmental changes. Ultimately, the goal is to gather indirect evidence regarding children's responses to amplification. Further validation of this tool is in progress, using automated vocal analysis.

Preliminary results from the Open and Closed Set Test (Ertmer et al. 2004) suggest that this measure is sensitive to early phonological differences between children with HL and age-matched peers with NH. In addition, young children are able to cooperate with the procedures, and the test may be adaptable to the audiological context. Further research will determine if this measure is predictive of later achievements in speech production and speech intelligibility.

Although further work is needed, results suggest that the use of morphological elicitation probes provides a more in depth description of children's morphological development than standardized language measures. This set of procedures appears to have clinical utility, and is sensitive to developmental differences between children with NH and those with HL. In addition, this set of probes may be useful in exploring empirical questions about the ways in which limitations in audibility and/or access to language input may influence the development of grammatical morphology in children with HL. Future longitudinal data from the OCHL study will be of assistance in determining the utility of these measures in addressing clinical and research goals.

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Appendix A: Structure of the Morphological Elicitation Procedure		
Warm Up Task: Phonological Probe - Child plays bingo game and is asked to name simple objects (e.g., bus, horse, nose, bed, foot). This ensures that the child is able to produce phonemes like /s, z, t, d/ at the end of words (a phonological skill that is needed for use of grammatical morphemes).		
Subtest	DVD Movie Scenario	Item Example
Singular/plural: Regular forms (cat/cats)	Opening presents, purses or treasure chest to find objects	Child opens gift and finds shoes. Prompt: What did he find? Target form: shoe**s**
Singular/plural: Irregular forms (foot/feet)	Opening presents, purses or treasure chest to find objects	Child opens treasure chest and finds fake teeth & puts them in his mouth. Prompt: What did he find? Target form: **teeth**
Possessive mom's, Joey's	Family folding laundry to put away	Oh look, mom is folding dad's shirt. Mom then takes baby dress from laundry. Prompt: Whose dress is that? Target form: It's ____ baby's
Third person singular (he wants)	Images of people in distinct roles; Child is asked to discuss what they do everyday	Look, here is a swimmer. Prompt: Tell me what he does every day. Target form: He _____ (swim**s**).
Irregular past tense (break/broke)	Children are completing everyday actions in a preschool. When actions finish, child is asked to talk about what the children did.	Two girls are blowing bubbles. They finish the action. Prompt: "What did they do?" Target form: They __ (**blew** bubbles).
Regular past tense (walk/walked)	Same as irregular, but regular verbs are depicted.	Child feeds baby doll, picks her up and kisses her. Action finishes. Prompt: "What did she do to the doll?" Target form: She _____ (kiss**ed** it).
Copula "be" (It **IS** _____)	Children are playing dress up. They are shown on the screen in various costumes. One picture is shown and accompanied by a model. Then the child responds to a second picture (parallel example).	(Boy in fireman costume). This boy is a fireman. Prompt: Tell me about the girl. Target form: The girl_____ (**is** a doctor).
Auxiliary "be" (it IS running) The verb "is" functions as a helping verb.	Children are baking cookies with their teacher. Various actions are performed in sequence.	A boy is cracking an egg for the cookie dough. Prompt: Tell me about the boy. The boy ____ (**is** breaking).
Progressive verb (go+ING)	Verbs produced in the Auxiliary section are checked for use of the +ing.	A girl is pouring water into the bowl. Prompt: Tell me about the girl. Target form: The girl _____ (is pour**ing**).