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Longitudinal Development of Phonology and Morphology in Children with Late-Identified Mild-Moderate Sensorineural Hearing Loss

Mary Pat Moeller, Ph.D., **Elizabeth McCleary, M.A.**, **Coille Putman, M.S.**, **Amy Tyler-Krings, M.A.**, **Brenda Hoover, M.A.**, and **Patricia Stelmachowicz, Ph.D.**
Boys Town National Research Hospital, 555 N. 30th Street, Omaha, NE 68131, (402) 452-5068, (402) 452-5029 (fax)

Mary Pat Moeller: marypat.moeller@boystown.org

Abstract

Objective—Studies of language development in children with mild-moderate hearing loss are relatively rare. Longitudinal studies of children with late-identified hearing loss have not been conducted, and they are relevant for determining how a period of unaided mild-moderate hearing loss impacts development. In recent years, newborn hearing screening programs have effectively reduced the ages of identification for most children with permanent hearing loss. However, some children continue to be identified late and research is needed to guide management decisions. Further, studies of this group may help to discern if language normalizes following intervention, and/or if certain aspects of language might be vulnerable to persistent delays. The current study examines the impact of late identification and reduced audibility on speech and language outcomes via a longitudinal study of four children with mild-moderate sensorineural hearing loss.

Design—Longitudinal outcomes of four children with late-identified mild-moderate sensorinueral hearing loss were studied using standardized measures and language sampling procedures, from at or near the point of identification (28 – 41 months) through 84 months of age. The children with hearing loss were compared to ten age-matched children with normal hearing on a majority of the measures through 60 months of age. Spontaneous language samples were collected from mother-child interaction sessions, recorded at consistent intervals in a laboratory-based play setting. Transcripts were analyzed using computer-based procedures (Systematic Analysis of Language Transcripts) and the Index of Productive Syntax. Possible influences of audibility were explored by examining the onset and productive use of a set of verb tense markers, and by monitoring the children's accuracy in use of morphological endings. Phonological samples at baseline were transcribed and analyzed using Computerized Profiling.

Results—At entry to the study, the four children with hearing loss demonstrated language delays, with pronounced delays in phonological development. Three of the four children demonstrated rapid progress with development and interventions, and performed within the average range on standardized speech and language measures compared to age-matched children by 60-months of age. However, persistent differences from children with normal hearing were observed in the areas of morphosyntax, speech intelligibility in conversation, and production of fricatives. Children with

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mild-moderate hearing loss demonstrated later than typical emergence of certain verb tense markers, which may be related to reduced or inconsistent audibility.

Conclusions—The results of this study suggest that early communication delays will resolve for children with late-identified mild-moderate hearing loss, given appropriate amplification and intervention services. A positive result is that three of four children demonstrated normalization of broad language behaviors by 60-months of age, in spite of significant delays at baseline. However, these children are at risk for persistent delays in phonology at the conversational level and for accuracy in use of morphological markers. The ways in which reduced auditory experiences and audibility may contribute to these delays are explored, along with implications for evaluation of outcomes.

Studies of language development in young children with mild-moderate sensorineural hearing loss (MMHL) are relatively rare. Existing studies suggest that some children with MMHL are at risk for language delays, particularly in areas such as phonology, morphology, and advanced vocabulary and syntax production (Borg, Edquist, Reinholdson, et al., 2007; Delage & Tuller, 2007; Elfenbein, Hardin-Jones, & Davis, 1994; Kennedy, McCann, Campbell, et al., 2006; Kiese-Himmel & Reeh, 2006; Wake, Hughes, Poulakis, et al., 2004). Most studies in the extant literature involve children whose hearing losses were identified late compared to contemporary standards (see Moeller, Tomblin, Yoshinaga-Itano, et al., 2007 for a review). These children presumably experienced varying periods of reduced or degraded input prior to the fitting of amplification, and this factor exerts influence on outcomes (Norbury, Bishop, & Briscoe, 2001). To date, the impact of these differences in early auditory experience on language development is not well understood. Prospective longitudinal analyses may be helpful in understanding how delayed access to amplification affects language, and whether children with MMHL may “recover” from initial delays once interventions are provided. Such questions remain relevant in the era of newborn hearing screening, because findings may provide indirect support for early identification and guide the management of children with MMHL who continue to be identified late.

There is some disagreement in the literature about the persistence of language delays associated with MMHL. Some suggest that even mild hearing loss places a child at risk for lasting language delays (Davis, Elfenbein, Schum, & Bentler, 1986), while others conclude that peripheral hearing impairment is ‘compensated for’ in many children with MMHL (Borg, et al., 2007). Delage and Tuller (2007) reported that 19 adolescents with MMHL were found to be at greater risk for language impairment than peers with NH, indicating that language delays do not necessarily normalize with age in this group. There also is disagreement about the prevalence of co-morbid language disabilities in this group of children (Borg, et al., 2007; Delage & Tuller, 2007; Gilbertson & Kamhi, 1995), but there is a consensus that their existence influences outcome. The overall pattern of equivocal results may be related to differences in characteristics of the samples (e.g., variation in periods without amplification, presence of co-morbid conditions) and measurement factors (e.g., ages examined, constructs measured, and sensitivity of measurement tools). A point of agreement across studies is the wide individual variation in outcomes, which speaks to the need for a better understanding of variables that influence outcomes over time in children with MMHL.

Selected aspects of speech and language may be particularly susceptible to the presence of MMHL and delayed access to amplification. Delage and Tuller (2007) drew upon the literature on critical periods (e.g., Newport, Bavelier & Neville, 2001 cited in Delage & Tuller, 2007) to suggest that formal aspects of language (phonology and morphosyntax) are more vulnerable in the face of protracted language development than vocabulary or semantics. Children with late-identified hearing loss spend a portion of critical language acquisition periods with degraded or partial language input, which may differentially affect phonology and morphology. There are consistent reports in the literature of delays in phonological skills (Elfenbein, et al., 1994; see Eisenberg, 2007 for a review) and verb morphology in this population of children (Delage & Tuller, 2007; Elfenbein, et al., 1994; McGuckian & Henry, 2007; Norbury, et al., 2001), which may lend support to the notion that these areas are vulnerable. Elfenbein and colleagues (1994) conducted a cross-sectional study of 40 students with mild to severe HL that included articulation measures. The common persistent errors observed in the speech of the children involved the production of fricatives and affricates.

Delays in mastery of verb tense marking also have been identified in children with MMHL (Delage & Tuller, 2007; Elfenbein, et al., 1994; McGuckian & Henry, 2007), but it is unclear if such delays resolve with age. Delage & Tuller (2007) identified disorders in phonology and morphosyntax in half of their French-speaking adolescents (n = 19) with MMHL, suggesting persistent difficulties in these susceptible areas. Norbury, et al. (2001) found that children with mild-moderate HL (ages 5–10; n = 19) performed similarly to children with NH on verb morphology tasks. However the youngest children with HL in their sample (n = 6) demonstrated difficulty with third person singular –s and past tense markers. The average age of hearing aid fitting for this sample was 48.2 months. The authors concluded that "disrupted auditory input during the time of normal language acquisition may delay the development of a number of different linguistic skills, including verb tense marking (p 175)."

In addition to atypical early auditory experience, limitations in audibility following intervention may continue to influence the development of both phonology and morphosyntax for children with MMHL. The limited bandwidth of hearing aids is known to affect perception and production of consonants in the fricative class (Moeller, Hoover, Putman, et al., 2007; Stelmachowicz, Pittman, Hoover, & Lewis, 2001, 2002). Children with MMHL (5–13 years of age) demonstrated highly variable perception of –s marking plurality compared to 3–5 year olds with NH (Stelmachowicz, et al., 2002). Because of reduced audibility, particularly in contexts of noise and reverberation, children with MMHL may receive inconsistent input about obligatory contexts for using morphological endings in English, complicating the process of rule formation. This may be particularly true for verb tense markers like third person singular (*She need**s** help*), that often occur in phrase-medial positions of sentences, which can reduce the overall amplitude of final consonants (Song, Sundara, & Demuth, 2009). If this is the case, it is hypothesized that forms like third person singular (/3s) will be more delayed than other tense markers for children with MMHL.

The order in which children with MMHL begin to mark for verb tense may hold clues to the contributions of audibility in morphological development. The onset and consistent use of verb tense marking has been studied extensively in children with NH, including both typically developing and those with language impairments. Researchers have been particularly interested in a small group of verb tense markers that form a coherent set in development and are sensitive to the identification of language impairment in children (Leonard, Miller & Gerber, 1999; Rice & Wexler, 1996). They include forms of the following verbs: (1) copula *BE* (My hat *is* red), (2) third person singular present tense (/3s - Joey run*s*), (3) auxiliary verb *BE* (The girl *is* jumping), (4) auxiliary *DO* (*Does* he like it?), and (5) past tense regular –ed (We walk/*ed*) (Hadley & Short, 2005). According to Hadley (2006), this group of morphemes is important because they share the role of marking the underlying grammatical feature of tense in sentences, even though they differ in their surface forms. In typical development, tense marking begins between two and one half years of age (Rispoli, Hadley & Holt, 2009), and all of the forms are present by three years for the majority of children with NH (Hadley, 2006; Hadley & Short, 2005; Hadley & Rice, 1996). It is of interest for the current analysis that third person singular (/3s) is among the earliest appearing tense morphemes for children with NH (Hadley, 2006).

Delays in use of verb tense marking and use of other morphological markers also may reflect instability in the children's phonological mastery of fricatives and production of final blends, like /kt/ in *walked* or /ts/ in *cats* (Song, et al., 2009). Phonology and morphology are interdependent aspects of development for all children. If both areas are vulnerable for children with late-identified MMHL, a better understanding of their joint influences on language development is needed.

The current study is a longitudinal descriptive analysis of selected aspects of phonology and morphosyntactic development in four children with MMHL who were late identified. Although the sample is small, longitudinal studies from the point of identification of this group of children are particularly rare. These cases represent a unique opportunity to address several questions: (1) What are the effects of a period of unaided MMHL on language development (based on measures at or near the point of identification)? This is of particular interest because it is not ethical to conduct a randomized controlled study where children are assigned to treatment and non-treatment groups. (2) What is the developmental order of verb tense marking and does it suggest influences of audibility on morphology? (3) Do early delays resolve with development and intervention, and if errors persist, are they in areas predicted to be vulnerable?

Method

Participants

Ten children with normal hearing (NH) and four children with late-identified bilateral sensorineural hearing loss (HL) participated in this study. The ten children with NH were followed from 4 to 60 months of age in a larger longitudinal study reported previously (Moeller, et al., 2007). The four children with HL also were enrolled in the larger longitudinal study, but entered at later ages (28–41 months range), following identification and hearing aid fitting and were followed until 84 months of age.

The NH group included five females and five males, who served as a comparison group for the late-identified children with HL. Normal-hearing status initially was based upon distortion product otoacoustic emission measures (DPOAEs) and later confirmed using visual reinforcement audiometry (VRA). At entry to the study, all children exhibited typical developmental milestones and were from homes in which English was the primary spoken language.

The group with HL included four children (one male) who were identified and aided late relative to contemporary practices (Mean = 30.2 months for identification; 31.5 months for hearing aid fitting). Specifc demographic information for these children is shown in the Appendix. All children had bilateral, mild-moderate sensorineural hearing losses. The mean left ear pure tone average (PTA) for the group was 47 dB HL (range: 38–55 dB HL); the mean right ear PTA was 40 dB HL (range: 18 – 54 dB HL). S2 and S4 did not pass NHS, but the information reportedly did not reach the families or managing physicians. S3 was the sibling of a child with profound hearing loss. According to parent report, he passed NHS, but had multiple congenital medical concerns. His hearing was retested following evidence of speech and language delays in the second year of life. The remaining child (S1) was born prior to the implementation of NHS in her state. Her parents reported that they began seeking audiological testing when their daughter was two years of age because she did not speak as clearly as the other children at day care. They reported that they suspected she had not heard normally since birth. Based on these histories, we assume that three of the four children had congenital HL, and S3 may have had onset of HL in infancy.

Depending upon age of enrollment, a combination of test techniques (VRA, conditioned play audiometry, and DPOAEs) was used to diagnose and characterize the children's hearing losses.

At the time of enrollment, the children with HL were observed to be developing normally in areas unrelated to speech/language/hearing. All of the children with HL were provided amplification within two months of the diagnosis (Mean = 1.3 months post-identification). Target gain values specified by the Desired Sensational Level procedure (DSL [i/o] v4.1) (Seewald, Cornelisse, Ramji, et al., 1997) were used in conjunction with probe-microphone measures of gain and output as a function of frequency to determine and validate hearing-instrument settings. All of these children were enrolled in early intervention or preschool services through local public or private education programs.

The distributions of scores for socioeconomic status for the two groups of children were completely overlapping. The SES Index was computed using both parental education and occupation, following Nittrouer and Burton (2005). The average SES scores were 39.5 (SD = 11.8) for the children with NH and 42.0 (SD = 18.8) for the children with HL. All children came from two-parent homes. Across both groups, 100% of participants were Caucasian.

Data Collection

A set of outcome measures was collected longitudinally from both groups of children. The first goal was to characterize the status of speech and language abilities at or near baseline in the children with MMHL compared to age-matched peers with NH. Areas of language predicted to be susceptible to the effects of MMHL (e.g., phonology, morphosyntax) then were monitored longitudinally in an effort to determine if children “recover” from early delays. Children with NH were seen at two month intervals between 4 and 36 months of age and at six month intervals thereafter until 60 months of age; children with MMHL enrolled prior to three years of age were seen at two month intervals between age of entry and 36 months. S1 and S2 participated at 6-month intervals from 36 – 84 months of age, whereas S3 and S4 participated at two-month intervals from 36–84 months.

At each visit, 20 to 30- minute parent-child interaction sessions were video and audio recorded in a laboratory playroom setting. Caregivers were asked to play with their child in a typical manner, using standard sets of age-appropriate toys. One child with NH and one child with MMHL (S4) were accompanied by fathers. The remaining subjects were accompanied by mothers. Children wore a fitted vest that had been adapted to hold a wireless lavaliere microphone (Shure Model LX1-V), positioned on the chest to maintain a consistent microphone-to-mouth distance of approximately 2 inches. Audio and video recordings were made with a Panasonic Professional AGDVC10P Mini-DV camcorder or a JVC SR-VS30 Mini-DV/S-VHS video record deck. The camera was mounted on a pan-tilt head that was controlled remotely from an observation room. This allowed researchers to follow the child’s movements about the room, while maintaining an unobtrusive observation context.

Verbatim transcripts of parent and child utterances were prepared for a portion of each session using *Systematic Analysis of Language Transcripts* (SALT; Miller & Chapman, 1991). Transcripts included 100 spontaneous child utterances, and were prepared by trained research assistants. All language transcripts were verified for accuracy by speech-language pathologists on the research team, who made additional passes through the DVD recordings and SALT transcripts. On the final transcript verification pass, the accuracy of each bound morpheme coding was verified.

At selected sessions, standardized language and speech assessment procedures were administered following the play session. These included a receptive vocabulary test (*Peabody Picture Vocabulary Test-III*; Dunn & Dunn, 1997), an articulation measure (*Goldman-Fristoe Test of Articulation-R*; Goldman & Fristoe, 2000), and a broad measure of receptive and expressive language development (*Preschool Language Scale-3*; Zimmerman, Steiner, & Pond, 1992). In a few instances, children with HL were tested in a quiet room at their school to accommodate parental schedules. All tests and procedures were administered in spoken language.

Measures At or Near Study Entry (baseline)

Two baseline measures were obtained: 1) accuracy of production of consonants and vowels in words, 2) a broad measure of receptive and expressive language development. Baseline measures of phonological skills were collected (at 28 [S2], 32 [S3], and 42 [S1[1]] and 41 [S4] months respectively) and compared to 10 children with NH at each age. Spontaneous speech samples were recorded during parent-child interaction sessions. A set of the children's spontaneous words or word attempts was subjected to broad transcription, conducted by a team of trained and experienced speech-language pathologists. In the current study, children's utterances were identified as *words* when: 1) the phonological characteristics of the child's production matched the word the child was trying to say for at least one consonant and at least one vowel and/or syllable structure matched, 2) the utterance was a communicative act, and 3) it was clear from the context that child was attempting a word (e.g., a clear referent was present or child was responding to a parental comment) and/or the parent recognized the word and/or repeated it (determined from context).

All utterances determined to be words were entered phonetically into Profile of Phonology (PROPH), a software application of Computerized Profiling (Long, Fey, & Channell, 2004). The PROPH analysis also was conducted on language samples from the children with NH for each of the entry ages of the children with HL (28, 32, and 42 months for a total of 30 NH speech samples). For this analysis only, 10 children's samples at each age were selected randomly from the longitudinal study database of 21 children with NH[2]. The goal was to analyze fifty consecutive spontaneous words in each sample, in an effort to collect a representative sample of words the child was producing. However, two of the four children with HL produced only a small set of words at their first session. S2's spontaneous sample included only 16 useable word attempts; S3's sample contained 21 useable words. In addition, because S2 produced few analyzable words, her attempts were accepted if her mother recognized them as words (e.g., phonetic criteria were relaxed for this subject only). Measures derived from this analysis included: 1) Percent Vowels Correct (PVC) in single word attempts, 2) Percent Consonants Correct (PCC) measured on single word attempts; this is an adaptation of a measure that compares the accuracy of the child's consonant production to the consonants in the target word (Shriberg, Austin, Lewis, et al., 1997; Shriberg & Kwiatkowski, 1982), and 3) PCC comprising the first eight consonants children typically master (/m, b, j, n, w, d, p, h/) and the middle eight consonants children typically master (/t, ŋ, k, g, f, v, tʃ, dʒ/: Shriberg, 1993).

Point to point reliability for broad transcription of consonants and vowels was assessed for 40% of the samples for the NH children (at each of the matched ages) and 100% of the samples for the children with HL. Inter-judge reliability for the NH group was 90.7% at 28 months, 92.6% at 32 months, and 92.43% at 42 months. Reliability was 83.5% (range = 79.4 – 85.5) for the children with HL. Lower levels of agreement may be a reflection of the phonological delays and/or instability in the children's word attempts at these ages. Disagreements were resolved through consensus transcription methods, using a team of two transcriptionists (Shriberg, Kwiatkowski, & Hoffman, 1984).

[1]S1 was identified at 38 months, but her 42 month sample was used so that she could be compared to the control group of children with NH (who were not tested at 38 months).

[2]The 10 NH children who served as a comparison group in this study were all included at one of the target age points, but additional children from the database were selected to have as wide a representation of phonological abilities as possible at each of the ages sampled.

A broad standardized measure of receptive and expressive language development was collected at the children's entry to the study. The *Preschool Language Scale-3* (Zimmerman, Steiner, & Pond, 1992) (n=3) or the *Reynell Developmental Language Scales* (Reynell & Huntley, 1985) (n = 1) was administered and standard scores were calculated.

Longitudinal Measures: Speech Production

The *Goldman Fristoe Test of Articulation-2* (Goldman & Fristoe, 2000) was administered to all children at 4 and 5 years of age and standard scores were derived. Protocols were examined for errors in the fricative class, which are expected to be vulnerable to delays in children with MMHL (Elfenbein, et al., 1994; Moeller, et al., 2007). Fricatives /s/ and /z/ are particularly important because they are used in English to mark certain verb tenses (*It's mine*; *She wants*), as well as plurality (*cat, cats*) and possession (*mom's hat*) on nouns. Therefore, protocols also were examined for accuracy of these phonemes in the postvocalic position of words to document if the children had the phonological skills to support production of morphological markers.

Because single word articulation measures may not reflect conversational speech intelligibility (DuBois & Bernthal, 1978), a broad measure of language sample intelligibility was included. Conventions in SALT were used to measure the overall intelligibility of the children's spontaneous utterances at ages 36–42 months (depending on age at entry), 48 and 60 months for the children with HL. The same measures were applied to the group with NH at 36, 48 and 60 months of age. Unintelligible and partially intelligible utterances were coded in the language transcripts using SALT conventions, and the percent of complete and intelligible utterances was automatically calculated by the program. Unintelligible segments were coded as X (single words), XX the boy (partially unintelligible utterances) or XXX (fully unintelligible utterances).

Longitudinal Measures: Morphology/Grammar

Child utterances in the longitudinal language samples were examined for the onset and productive use of four target verb tense markers: copula BE, third person singular (/3s), auxiliary DO, and auxiliary BE. Children's uses of these forms were identified in SALT. Although researchers typically also include the past tense /ed in the set when analyzing verb tense marking, references to past did not occur frequently enough in the spontaneous samples of the current study to support analysis. Two measures related to the other four verb tense markings were obtained from the language samples, following Hadley and Short (2005): 1) ages at which children first showed two distinctive uses of each individual form, and 2) initial productive use of all four forms, defined as the sampling age at which all four forms were used in at least two different ways (e.g., /3s on different verb stems - *eat/s* and *need/s*; or copula with two different noun phrases - *boy is hungry* and *he is hungry*). Also following their rules, forms that were contracted to pronouns (*It's* a ball; *What's* that?) were excluded because of the risk for over-crediting the children for unanalyzed forms (i.e., learned as whole units tied to familiar pronouns). The 36-month samples for the NH children also were examined for initial productive use of all four target tense markers. Finally, automated analyses in SALT were used to calculate the number of morpheme errors and error types as a function of age for the children with HL.

Language samples also were analyzed for grammatical development beyond morphology. The *Index of Productive Syntax* (IPSYN; Scarborough, 1990) was computed for the 36–41 (depending on the child's age of entry to the study), 48, and 60[3] months samples. The IPSYN

[3]One child (S2) was seen at 70 months for the 60 month sample because of family schedule conflicts. In her case, IPSYN was completed on the 54 and 70-months samples, and the 60-month score was estimated using interpolation.

is a method for evaluating the grammatical complexity of language samples using developmental ratings of structures in the categories of noun phrase, verb phrase, question, negation, and sentence structure. IPSYN was completed on 100-utterance language samples, as recommended by Scarborough (1990). If fewer than 100 codable utterances were available for individual children, IPSYN scores were estimated using conversion norms from Scarborough (1990)[4].

Longitudinal Measures: Standardized Language Battery

Standardized measures of vocabulary (*Peabody Picture Vocabulary Test-III*) were collected at 4, 5 and 6 to 7 years. *The Preschool Language Scale -3*, administered at baseline, was re-administered to the children with HL at 6 to 7 years of age to assess global changes in receptive and expressive language.

Results

Results are presented for the baseline measures, followed by analysis of longitudinal changes in phonology and morphology/grammar. The section ends with a summary of standardized outcome measures. For the majority of analyses, statistical comparisons of the groups are inappropriate due to the small number of children with MMHL and imbalanced group sizes. In order to make meaningful comparisons, individual subject data for children with MMHL are plotted relative to the mean values and 95% confidence intervals for the ten children with NH. In some cases, means are derived for three of the children with HL, because their performances on the variable of interest were homogenous. In contrast, measures for S2 were not representative of the other children, so they were handled separately.

Baseline Performance

Results of the children's status at or near study entry are relevant to understanding the effects of a period of unaided MMHL on language development. All four late-identified children entered the study with phonological skills that were significantly delayed relative to age-matched peers, with consonants more delayed than vowels for three of the four children. As shown in Fig 1, all four children with HL scored well below the 95% confidence interval for the NH children on the percent consonants correct (PCC) measure at baseline. Two children's (S2, S3) scores were well below the NH confidence interval for vowel accuracy (PVC), while the other children (S1, S4) scored below, but close to NH peers. When consonant accuracy was analyzed by developmental order (first 8, mid 8), three children demonstrated a developmental pattern, with early consonants more accurate than mid-developing consonants. S3's scores fell well below the confidence intervals for both sets, diverging from the NH group even further for the first 8 consonants. A review of the children's consonant inventories produced at the word level revealed a predominance of early-appearing stops, glides, and nasals /(b, p, m, n, w, j/) and mid-level stops (/t, d, k, g/). Fricatives and affricates, with the exception of /h/, were rarely observed (only two total productions observed across the four children).

Results of standardized language testing revealed that only S1 was in the average range for receptive language at baseline (SS = 113); S3 and S4 performed 1.5 standard deviations below the mean for their ages, while S2 was greater than 2 standard deviations below age mates. In expressive language, the mean standard score for three children was 77.3 (SD = 1.5), which is approximately 1.5 standard deviations below the mean for NH children. S2's delays were more extensive than the other children with HL.

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[4]A total of four and three scores were converted at 36 and 48 months of age respectively. All 60-month samples were 100 utterances in length.

In summary, baseline measures revealed that the children with late identified MMHL showed delays relative to age-matched children with NH in phonology (especially for consonants) and in expressive language. Three of four children demonstrated delays in receptive language.

Longitudinal Results: Speech Production Skills

All children with MMHL demonstrated fewer articulation errors at age five than at age four. Standard scores on this measure are summarized in Table 1. Two (S1[5], S3) achieved standard scores in the average range by 4 years of age, while the remaining two children scored more than two standard deviations below age mates. By five years of age, three of the four children with MMHL performed within the average range on this measure (X = 98.3). Table 1 also summarizes the number of fricative errors relative to total errors (in words without blends) made by the children with MMHL compared to the NH group. With the exception of S2, fricative errors were represented more than other error types, and (with the exception of S1) were more frequent than in the protocols of the NH children. The children with NH made few errors in postvocalic /s/ and /z/ at these ages, whereas three of the four children with MMHL omitted them at four years of age and two children did so at five years of age (See Table 1).

Patterns of fricative errors were compared across the two groups and differences were observed. The most frequent error type observed in the samples of children with HL was substitution of stops for fricatives. The second major error type was omission (especially in the postvocalic position or in blends). For the children with NH, stopping errors were observed infrequently for 9/10 subjects. Errors for the NH children were commonly substitutions of a fricative for another fricative or lateralization or fronting of fricative productions.

Performance on the GFTA-2 is not likely to fully represent how children with HL perform in terms of accuracy in conversational speech (DuBois & Bernthal, 1978; Ertmer, in press). The children all attended regular speech therapy sessions and were practiced in producing target phonemes in single word contexts. Therefore, estimates of intelligibility of utterances produced in conversation were taken from the SALT samples. As shown in Fig 2[6], both groups showed improved performance with age in intelligibility of spontaneous utterances. For the children with HL, the largest change was observed between 48 and 60 months. Group means for percent of unintelligible utterances in conversational samples were compared using nonparametric statistics (Mann Whitney U). Significant between-groups differences were observed at each of the test ages (36 months, $p = .008$; 48 months, $p = .002$, and 60 months, $p = .008$).

Longitudinal Measures: Morphology/Grammar

Verb Tense Marking—Both onset and productive use of verb tense marking were delayed in the children with MMHL. Table 2 summarizes the ages at which verb tense marking for each of the four target forms (/3s, copula, auxiliary BE and DO) was first observed (in at least two different forms). Notably, the third person singular tense marker (/3s) was later to emerge relative to most other forms in the samples of these children, and later than expected in typical development (around 26 months). For three of the four children with HL, initial productivity with all four forms (see far right column in Table 3) was identified closer to 4 years of age (and S2 showed more extensive delay). Nine of the 10 children with NH in the present study demonstrated productive use with all four forms by 36 months of age. Because these samples were recorded 2–6 months apart, the ages in Table 2 may not reflect precise development time

[5]Notably, S1 received a Standard Score of 76 on this measure at 38 months of age.

[6]S2 was excluded from this figure, because her scores were significantly lower at 60 months than the other three children and would be overrepresented in the average. In addition, her scores at earlier ages are difficult to compare to the others because her utterances were much shorter. S2 scored 51%, 68% and 52% at 3, 4 and 5 years. Her intelligibility score dropped as sentence length increased (at 60 months).

points. However, the results suggest that the children with HL were delayed relative to the children with NH.

Persistent delays in phonology (especially for postvocalic /s/ and /z/ and postvocalic blend production) would be expected to affect the accuracy of verb tense marking, especially for the third person singular form (/3s) (Song, et al., 2009). On standardized articulation measures, three of four children made production errors on postvocalic /s/ and /z/ at 48 months; two of the four children omitted final /s/ and /z/ at 60 months. Figure 3 illustrates a comparison of two children (S3, S4) on the level of accuracy of each of the four target tense markers as a function of age. Data for these two children were selected to contrast the performance of a child with stable production of /s/ and /z/ at 48 months (S3) to one with errors through 60 months (S4). Results for S3 show 80% accuracy or better for tense marking after 50 months of age. Notably, the /3s verb tense marker was the latest to be used consistently. Results for S4 show that three of the forms did not stabilize until 72 months of age; the /3s form remained inconsistent through 84 months of age. Notably, children with NH are observed to accurately produce noun and verb endings in the majority of obligatory contexts in the age range of 4–5 years (Rice, Wexler, & Hershberger, 1998).

Three of the children with MMHL made persistent errors in morphology after 54 months of age (when children with NH rarely make errors). One exception was S3, who made no errors in verb tense or noun morphology beginning at 52 months of age. He maintained a high degree of accuracy through 84 months of age. S1, in contrast, demonstrated errors through 78 months of age in spite of age-appropriate mean length of utterance (MLU) and articulation skills. S4 also demonstrated age-appropriate MLUs, but made morphological errors through 84 months of age. S2 was latest to develop verb tense marking and she made multiple morpheme omissions through 84 months of age. The most persistent error types (still evident after 54 months of age) for these children included the following verb tense markers: third person singular (/3s), contracted copula (*It's a*) and auxiliary (*He's going*), and past tense (*walk+ed*). All three also showed inconsistent marking of plurality on nouns (*cat/cats*).

Grammar—IPSYN total scores for all four children with HL fell below the lower limits of the 95% confidence interval for NH children at the first test interval (See Fig 4). Longitudinal data for each child with MMHL are plotted in comparison to the age-matched children with NH. Because two of the four (S1, S4) children with HL entered the study after 36 months of age, their first data points were taken from samples at 38 and 41 months respectively. Scores for three of the four children fell outside the average range at 48 months of age, reflecting delays in grammar production at least through this age. However, the scores for these same children converged with the average range by 60 months of age. S2 demonstrated slow growth in overall IPSYN scores over the entire longitudinal test period. Changes in her scores were not appreciable until the 60 month sample[7], and even then remained well below the other children in the study. In general, the IPSYN results support the findings of delayed onset and productivity for verb tense markers. The IPSYN analysis at 48 months confirmed delays in the children with MMHL in use of verb tense marking for: (1) /3s, (2) past tense +ed, and (3) Do auxiliary. Limited use of wh-clauses (*Here's where it went*) also was observed, suggesting delays in complex syntax. By 60 months, the three more advanced children with MMHL were comparable to the children with NH on the majority of forms, with the exception of past tense forms.

[7]S2 contributed samples at 54 and 70 months of age, but was not able to attend the 60 month session. For this analysis, her scores were estimated based on interpolation from the 54-month and 70-month session data. It was reasoned that 54 months would underestimate her skills, but 70-months would overestimate them.

Standardized Measures

The results of standardized test measures are presented in Table 3. Mean scores are presented for S1, S3 and S4, while individual scores are given for S2. Three of the four children performed within the average range on vocabulary and receptive-expressive language abilities at the 5 and 6–7 year test intervals. These results suggest that most of the initial delays observed at baseline resolved for three of the four children in this group. S2, who was the most delayed of the group at baseline, remained two standard deviations behind at the final test period, with articulation more delayed than the other areas.

Discussion

The longitudinal outcomes of four children with late-identified hearing loss were compared to age-matched peers in order to understand the impact of late identification on language development, to determine if language skills normalize with age, and to explore the effects of reduced audibility on phonology and morphology. Prior to intervention, late-identified children with mild-moderate sensorineural hearing loss receive exposure to language, but this exposure may be inconsistent (due to difficulties hearing at distance), and/or degraded (due to the effects of sensorineural hearing loss, noise, and reverberation: Delage & Tuller, 2007). At baseline testing, all four children with late-identified HL showed marked delays in phonology compared to age-matched peers with NH. The consonantal inventories of the four children were dominated by the consonants known to be early-appearing in development, along with alveolar (t/d) and velar (k/g) stops. Their inventories were notable for the absence of fricatives, which may be a consequence of both reduced auditory experience and limited audibility of this class of phonemes (Stelmachowicz, et al., 2001, 2002). Standardized measures of expressive language revealed delays at baseline for all four children; three of four were significantly delayed on a receptive language measure.

Do spoken language skills normalize with age?

One of the focal questions posed by this study was whether speech and language behaviors normalized with age in this group of children. Results of standardized measures of articulation skills indicate that three of the children (S2 excluded) made rapid progress with age, development, and fitting of amplification. Progress was reflected in standard scores that improved from 1.5 standard deviations delayed at baseline to within the average range by 4 to 5 years of age. Care must be taken in interpreting this result, however. Previous studies on children with speech impairment reveal that children make fewer errors in single word productions than they do in sentence or conversational contexts (DuBois & Bernthal, 1978), and this finding recently was replicated in children with hearing loss (Ertmer, in press). Based on their standardized articulation test scores, these three children may not qualify for speech therapy services. Yet, at 5 years of age, these children had significantly more unintelligible segments in their conversational speech than age-matched peers with NH. These findings support those of Ertmer (in press) and the practical implication is that intelligibility measures should be combined with single word articulation tests to identify areas of persistent need for these children. In general, three of the children demonstrated normalization of articulation skills in a single word context, but persistent challenges in speech intelligibility. Future research should determine whether earlier identification and provision of newer amplification technologies can ameliorate persistent delays in conversational speech intelligibility.

The analysis of error types on the *Goldman-Fristoe* supports the impression that the fricative class is particularly vulnerable in this group of children (Elfenbein, et al., 1994; Moeller, et al., 2007; Stelmachowicz, et al., 2001, 2002). In addition to appearing later in the consonant inventories, fricative errors were more common at 4 and 5 years of age in the children with MMHL (except for S1) compared to the children with NH. Further, the fricative error types produced by the children with MMHL differed from the children with NH. Substitutions of stops for fricatives and omissions of fricatives may have had their basis in perceptual challenges for children using amplification. Stelmachowicz, et al. (2001) documented that the restricted bandwidth of hearing aids limits the audibility of /s/, especially for female and child talkers. They concluded that children who wear hearing aids may hear a final /s/ when spoken by a male, but not by a child or female talker. This could create challenges for children's attempts to self monitor their productions, particularly for low amplitude final consonants. The children in the present study did not have access to newer amplification technologies that attempt to resolve this concern with nonlinear frequency compression. Therefore, it is possible that reduced audibility contributed to protracted emergence and prolonged inconsistency of use of this class of phonemes.

Standardized measures of receptive and expressive language and vocabulary demonstrated that three of the children resolved early delays by the late preschool years. The IPSYN results confirmed the pattern of normalization for broad aspects of grammar by 60 months of age for these same three children. It is positive to note that these three children demonstrated rapid changes in multiple aspects of speech and language development with age, amplification and intervention. This is particularly noteworthy, given how variable the children were at the onset of the study. For the three children who used hearing aids consistently and had access to all the therapeutic input, the outcomes are remarkably similar and quite positive. However, it is important to keep in mind that the standardized measures fell short in pinpointing some of their persistent needs in phonology and morphology – those areas predicted to be vulnerable in this population due to reduced auditory experience and audibility.

The outcomes for S2 were concerning, as she experienced greater developmental challenges in speech and language development than the other children with MMHL. Psychological evaluation documented that she had age-appropriate cognitive abilities. Importantly, this child was the only participant with a pure tone average > than 50 dB HL. In addition, her parents and school reported highly inconsistent use of amplification during the course of the longitudinal study. The child wore her amplification primarily during school hours and rarely at home. Essentially, this child differs from the other children with MMHL in that she was not receiving the full intervention and had the greatest hearing loss. These factors likely contributed to her slower learning rates in spoken language. They underscore the value of consistency in interventions.

Does audibility contribute to vulnerability in morphosyntax?

The longitudinal analysis of verb tense marking provides further insight into the possible contributions of restricted experience and/or audibility to morphology delays. The children with MMHL demonstrated delayed onset and productive use of all verb tense markings compared to children with NH. This provides additional support for proposals that disruption in the auditory input during early language acquisition could delay the development of linguistic skills like verb tense marking (Delage & Tuller, 2007; Norbury, et al., 2001). The longitudinal results for specific verb tenses suggest that limitations in audibility may combine with reduced auditory experience to influence the emergence of morphology. For all four children, the third person singular (/3s) tense marker (Mom *needs*) was later to emerge than verb tense markers that are likely to be more audible in the input (*is, does, am*). Previous research with typically developing children demonstrates that /3s is among the first tense markers (with copula BE and Auxiliary DO) to emerge, usually around 26 months of age (for a review see Hadley, 2006; Klee, Gavin, & Letts, 2002). The children with MMHL in the current study were first observed to produce these forms close to four years of age (and much later for S2). The /3s emerged several months after the appearance of copula BE and auxiliary DO for all of the children.

Three of four children (not S3), demonstrated persistent errors in use of /3s after 60 months of age, and two children (S2, S4) continued to make errors as late as 84 months of age. By four to five years of age, children with NH are fairly stable in the use of basic grammatical morphemes (Rice, et al., 1998). Past tense markers (*walk+ed*) were not analyzed in detail in the current study because they were relatively infrequent in the samples. However, when children attempted to talk about past, omission of +ed was frequent. These results concur with those reported by Norbury et al. (2001), who used elicitation procedures to document delays in use of /3s and past /ed in children with MMHL. Other persistent errors included contracted forms of the copula and auxiliary involving /s/and /z/ as well as plural markers on nouns. This latter finding is consistent with the experimental results of Stelmachowicz et al. (2002), who found variable production of plural marking in children with MMHL. The later accuracy for /3s and past /ed also was observed in children with moderate HL by McGuckian & Henry (2007), who suggested a role for input frequency in explaining these delays. For the /3s verb ending, it is conceivable that there are multiple influences on quality of input received by children with MMHL, including input frequency, effects of sentential position (Song, et al., 2009), limited bandwidth of hearing aids (Stelmachowicz, et al., 2001, 2002), and noise and reverberation. If the input is variable, children may have difficulty forming a rule for marking this verb tense, or they may surmise that marking is optional. Other types of input (like reading) may contribute to later stability of the rule application. The IPSYN results supported the view that morphology rather than broader aspects of grammar was vulnerable in this group of children. Three of the children demonstrated normalization of broad aspects of grammar by 60 months of age, but morphological errors similar to those described in the language samples were identified.

An alternative explanation for inconsistencies in morphological rule production in this group relates to the contribution of phonological delays. Song and colleagues (2009) demonstrated a role for phonology in explaining the variable accuracy in marking of the /3s in typically developing children between the ages of 1;3 and 3;6 years. Children were more accurate in marking verb tense in phonologically simple contexts (e.g., *sees* where a final blend is not required) as opposed to complex contexts (e.g., *wants*, which requires a /ts/ blend). The errors made at later ages by the children in the current study reflected both simple and complex final sound contexts. It may be for children with MMHL that the complexity of final blend production contributes to inaccuracy, along with the difficulties in self-monitoring of production due to audibility issues. Late emergence and instability of production of fricatives at the conversational level also may contribute to inaccuracies in tense and noun marking by these children. S3, who was earliest to master fricatives, was the only child in this study who accurately marked verbs and nouns by five years of age. Although S1 produced /s/ and /z/ accurately on an articulation test, she frequently omitted these phonemes in running speech, which contributed to reduced intelligibility and morphological omissions. The remaining two children demonstrated fricative omission on both the standardized test and in spontaneous language. It appears from the overall results that several factors may complicate the development of morphemes for late-identified children with MMHL: 1) audibility of final consonants especially in blends, 2) production of fricatives, which may have been affected by limited bandwidth of hearing aids, 3) differences in uptake from the input depending on the level of noise and reverberation, 4) the complexity of the production context, and 5) an early sensitive period without the benefits of amplification.

Although this study cannot distinguish among these possible influences, the results are suggestive of multiple influences. Future studies with early-identified children are key to disambiguating the relative contributions of these factors. It remains to be seen if early identification and technological advances in amplification (e.g., nonlinear frequency compression) will ameliorate these error patterns (Scollie, Glista, Bagatto, et al., 2007).

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Longitudinal studies at BTNRH are exploring this question in a new generation of hearing aid users with access to early interventions.

Conclusions

A positive finding from this study is that three of the four children demonstrated systematic improvement in speech and language skills with age and intervention. At baseline, all four children demonstrated significant speech and language delays, which largely resolved for three of them by the late preschool years. The results identified some persistent delays, however, in the areas of speech intelligibility, phonological skills (especially fricatives) and morphology. This paper has suggested that limited audibility may contribute to developmental vulnerabilities in these areas for children with MMHL. Although labor-intensive analyses of language samples are impractical for clinical use, this study points to some areas where standardized tests may need to be supplemented. Test batteries should include measures or probes of the following areas: (1) Verb tense marking and noun morphology. Clinicians and researchers may want to include elicitation probes or a formal test of verb tense marking (Rice & Wexler, 2001) when examining developmental outcomes of children with HL. (2) Speech intelligibility. Single word articulation measures may overestimate how children with MMHL will perform at the conversational level (Ertmer, in press). (3) Fricative development. Stability of fricative production at the conversational level may influence morphological accuracy; articulation measures can be analyzed for fricative accuracy and compared to spontaneous utterances. (4) Consistency of hearing aid use. Future research with early-identified children may help to clarify the contributions of reduced auditory experience and audibility on specific developmental trajectories.

This prospective, longitudinal study examined speech and language outcomes of four children with late-identified, mild-moderate, sensorineural hearing loss, compared to 10 children with normal hearing. Purposes of the study were to determine the degree to which initial delays resolved over time, and whether phonology and morphology were vulnerable to persistent delays. Results of standardized measures showed that initial delays resolved by five years of age for three of the four children. However, persistent delays were observed in phonology and accuracy of morpheme use. Ways that auditory experience and audibility may contribute to susceptibility in these areas of development are discussed.

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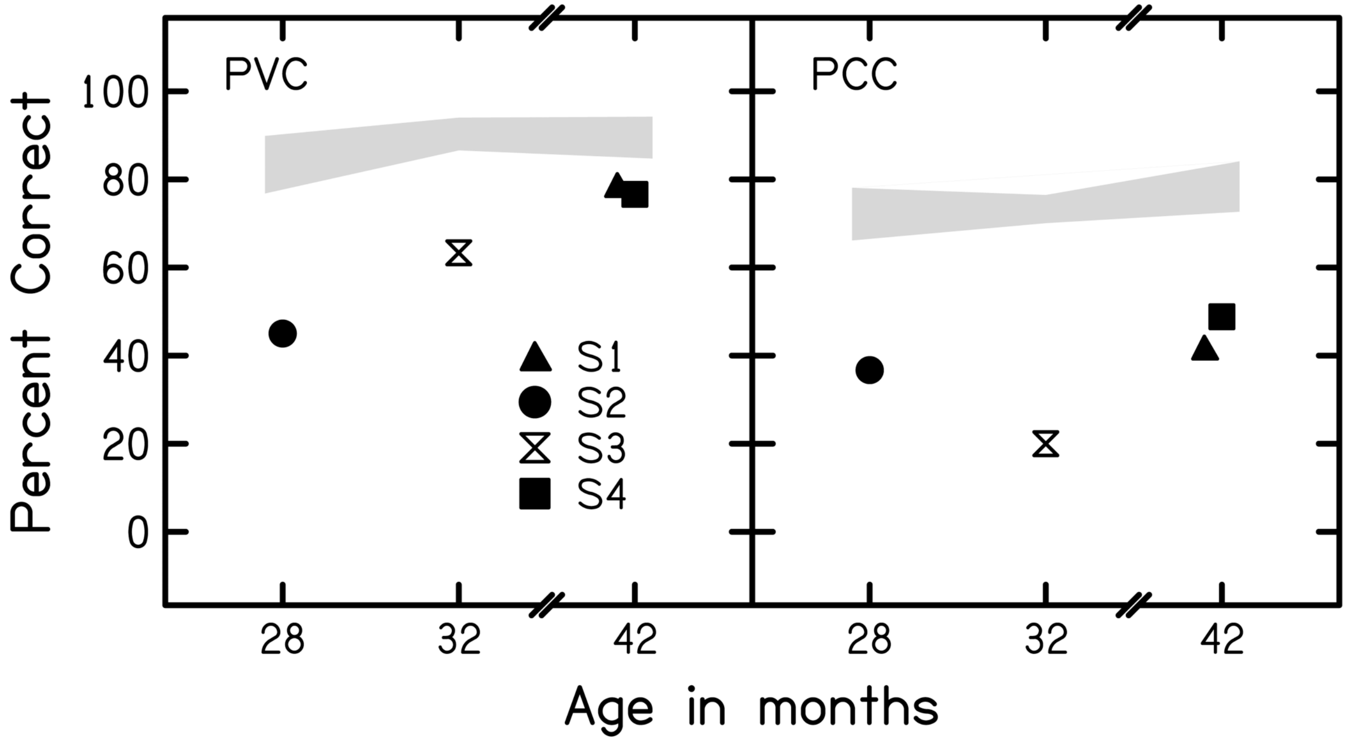

Fig 1.
Consonant and vowel accuracy in the words or word attempts produced by the children with HL at or near their first session in the study (which was close to their ages of identification). Grey areas signify the 95% confidence interval for 10 children with NH on the same measures. PVC = percent vowels correct; PCC = percent consonants correct.

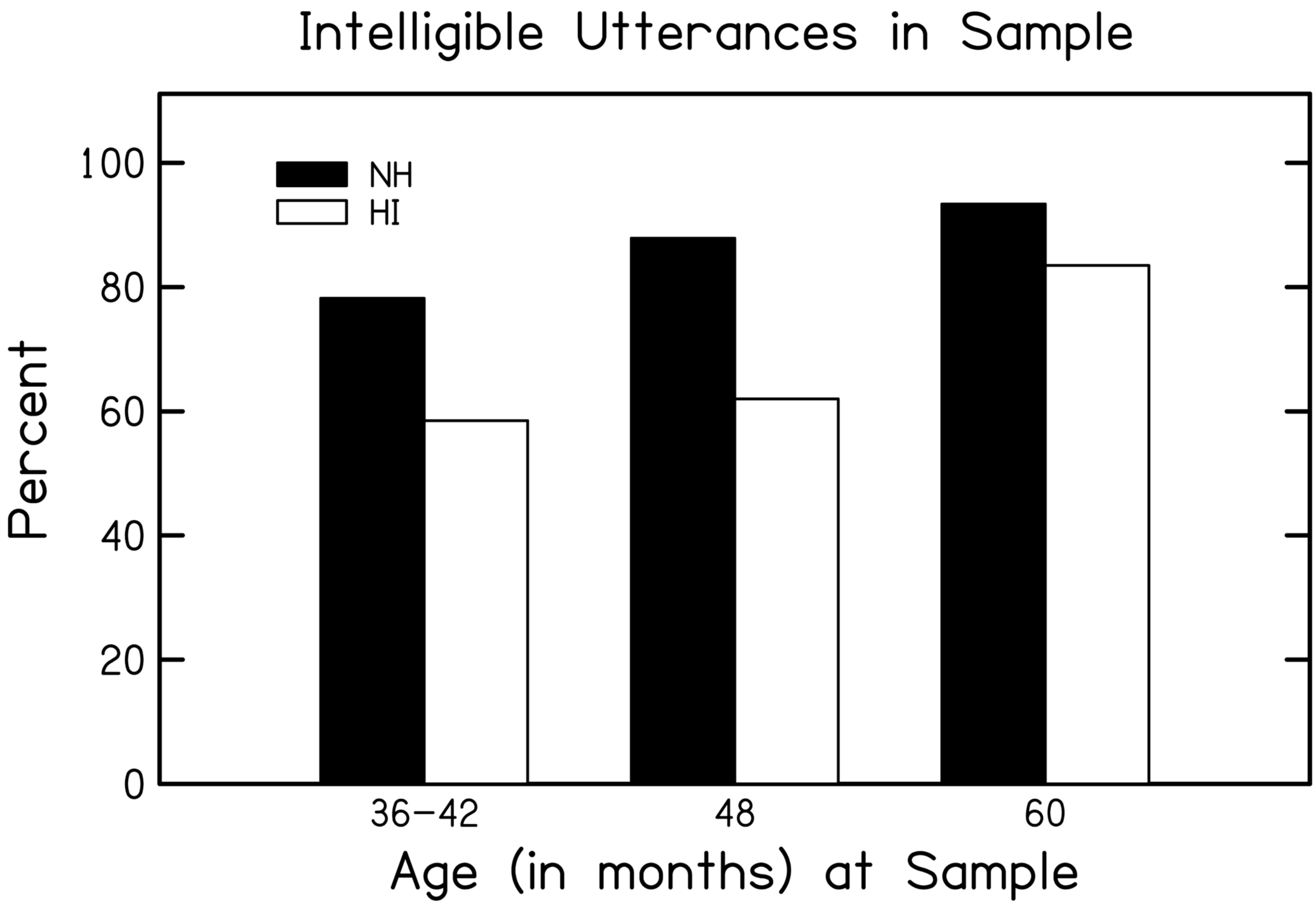

Fig 2.
Percent of utterances judged to be fully intelligible in spontaneous language samples for three children with HL (S1, S3 and S4) compared to 10 children with NH as a function of age.

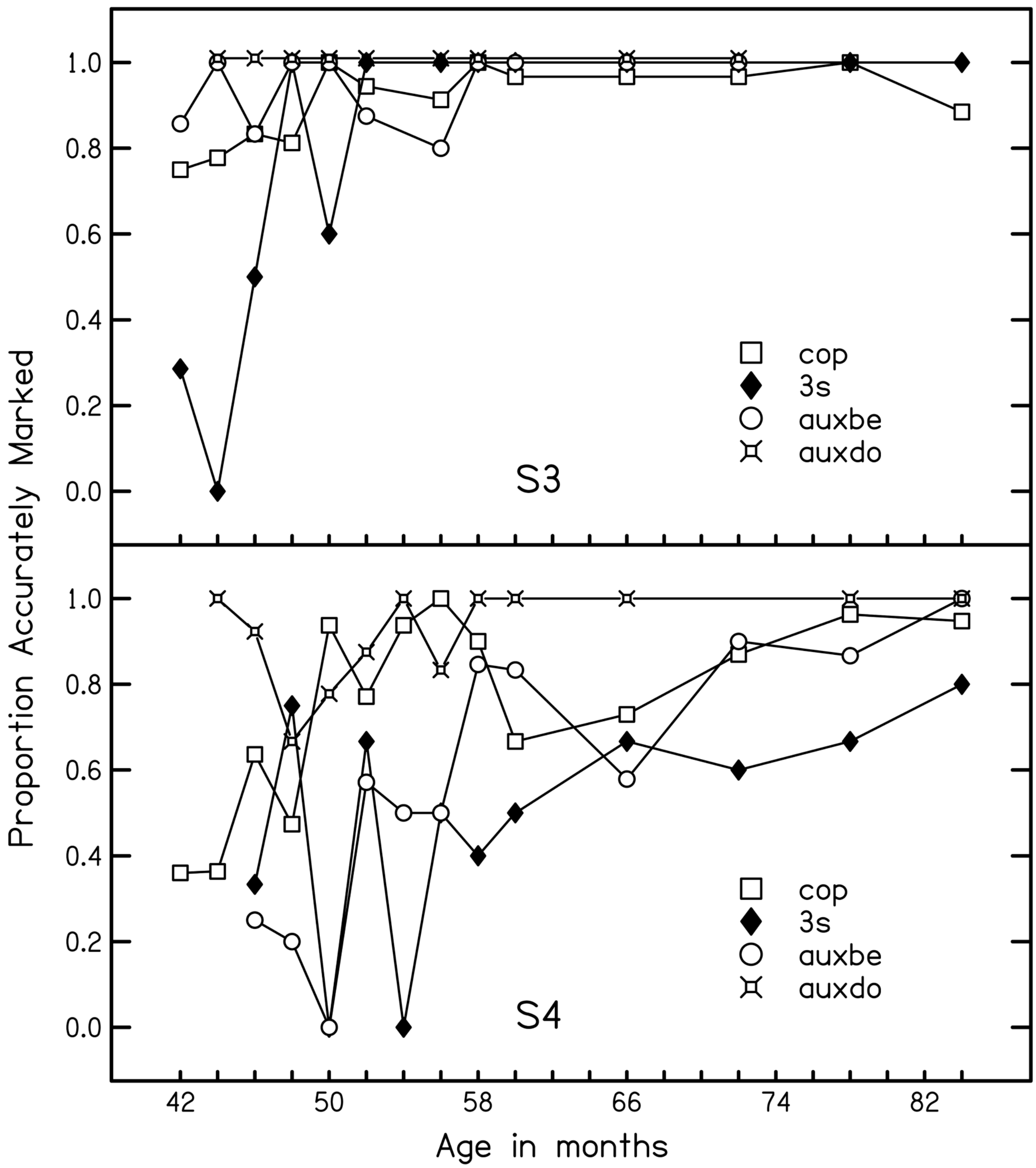

Fig 3.

Accuracy of marking of four verb tenses for a child with phonological mastery of /s/ and /z/ (S3) compared to a child with persistent phonological errors on /s/ and /z/ (S4). Recall that children with NH are observed to accurately produce noun and verb endings in the majority of obligatory contexts in the age range of 4–5 years (Rice, Wexler, & Hershberger, 1998). Cop = copula (Sally *is* four now); 3s = Third person singular (He need*s* some water); Auxbe – Auxiliary BE (John *is* going to school); Auxiliary DO (Molly *does* like school).

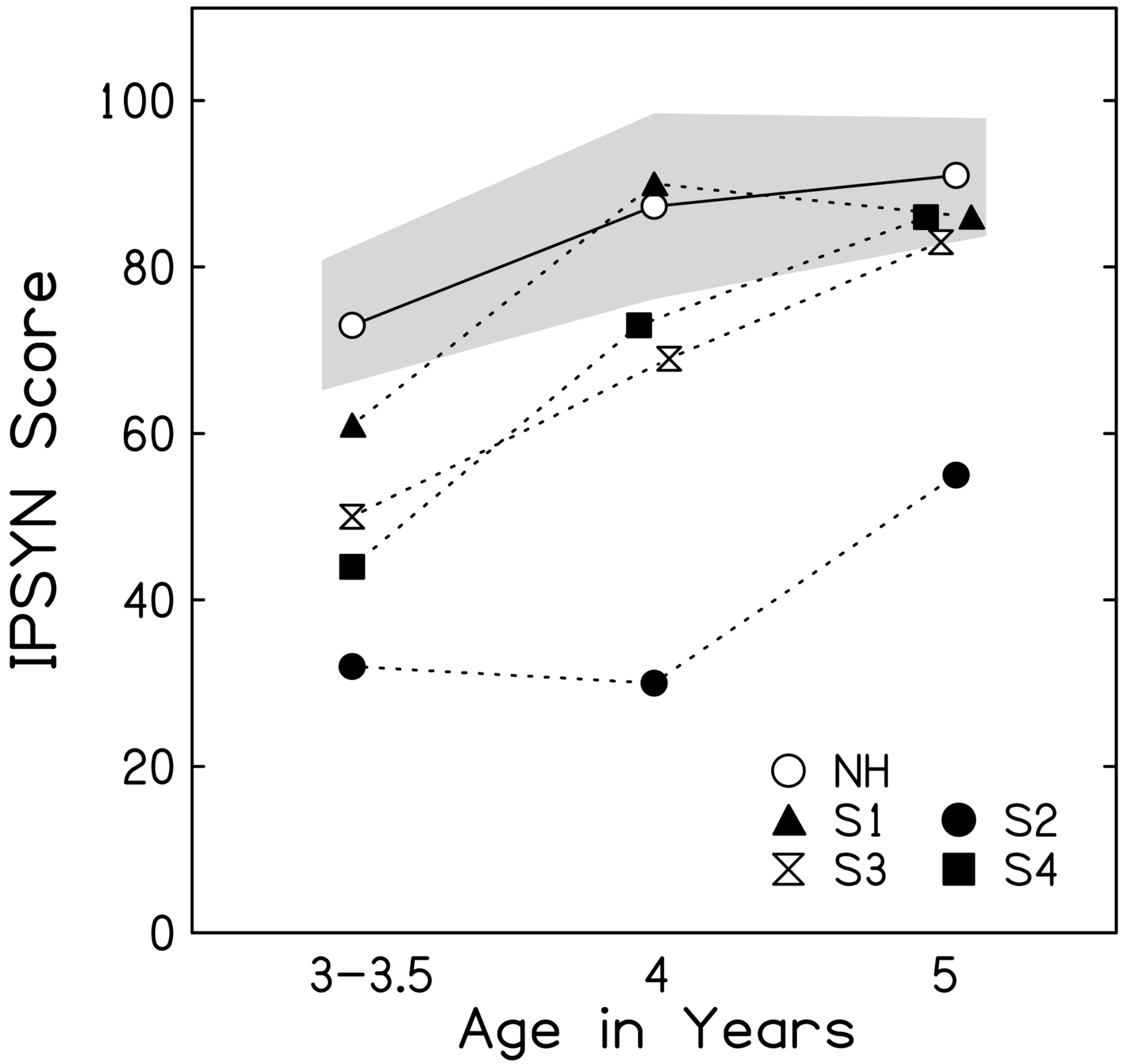

Fig 4.
Total IPSYN scores for each child with HL compared to the mean and 95 % confidence interval for the NH group as a function of age.

Table 1

Standard scores and number of fricative errors on the *Goldman-Fristoe Test of Articulation* compared to the total errors (blends are excluded in error counts).

	4 Years		5 years	
	G-F Standard Scores	**Fricative Errors/ All Errors**	**G-F Standard scores**	**Fricative Errors/ All Errors**
S1	109	3/5 +	106	2/3+
S2	44	17/46	47	13/31
S3	92	19/29	97	10/12+
S4	66	17/19	92	4/8
NH	102.6	5/9.5+	104.2	2.4/3.7+

+produced final s/z in words on the articulation test;

G-F = *Goldman Fristoe Test of Articulation*-2

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Table 2

Ages (in months) when two distinct uses of verb tense marking were first observed in the language samples (following Hadley & Short, 2005) and the ages when all four forms were present in the samples (right-most column).

	Cop BE (That *is* a cup)	/3s (He need*s* milk)	Aux DO (These *do* have holes)	AUX BE (He *is* running away)	Age at Tense Diversity*
S1	38	48	42	38	48
S2	54	78	54	78	78
S3	38	46	42	42	46
S4	41	50	44	50	50

*Tense diversity = sampling age at which child used at least two examples of each category of verb tense marking.

Table 3

Standard scores achieved on standardized language measures as a function of age. Means and standard deviations are presented for S1, S3, and S4; S2's results (atypical of the other children) are presented below the group means.

Measure	4 years	5 years	Final (6 years-7 years)
PPVT-III	92 (13.9) S2 = 68	97.6 (8.6) S2 = 76	97 (8.7) S2 = 70
PLS-III Receptive			114.3 (2.3) S2 = 74
PLS-III Expressive			118 (5.2) S2 = 72

Appendix A

Background characteristics of participants.

Subject #	Age of ID (mos)	Age Aided (mos)	Study Entry Age (mos)	Number of longitudinal samples	Circuit (L/R)	Gender	Program
S1	37	38	38	9	WDRC	female	Private oral
S2	25	26	28	11	WDRC	female	Public oral
S3	20	21	32	19	WDRC	male	Public oral
S4	39	41	41	15	CL	female	Private oral

WDRC = Wide dynamic range compression; CL = compression limiting

Appendix B

Threshold values for left and right ears (250 – 8KHz) for participants.

	Threshold (L/R)						
Subject #	250	500	1000	2000	4000	8000	Four Frequency PTA (L/R)
S1	25/40	30/40	55/50	55/60	55/55	60/60	49/51
S2	35/20	45/45	55/50	65/60	55/60	70/65	55/54
S3	60/45	50/30	65/15	50/15	20/10	30/35	46/18
S4	25/35	25/25	20/15	50/40	55/65	60/65	38/36
Mean							47/40

L/R = left/right ears.