Language Growth in Children with Mild to Severe Hearing Loss who Received Early Intervention by 3 Months or 6 Months of Age

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Abstract

Purpose: To evaluate the impact of hearing screening, diagnosis, and early intervention (EI) by 3 months or 6 months of age on language growth trajectories for children with hearing loss (HL) relative to children with normal hearing (NH).

Method: We recruited 133 children with mild to severe HL through universal newborn hearing screening records and referrals from audiologists in the United States and 116 children with NH who served as a comparison group. Examiners administered a battery of developmentally appropriate language measures between 12 months and 8 years of age. We constructed latent growth curve models of global language, grammar, and vocabulary using Bayesian statistics.

Results: Children with HL demonstrated no significant differences in initial language skills compared to children with NH. Children in the 1-3-6 group also showed no difference in language growth compared to children with NH. The slope for the 1-2-3 group was significantly steeper than children with NH for global language and grammar.

Conclusions: This study documents the positive impact of EI on language outcomes in children with congenital HL. It is among the first to provide evidence to support the potential effects of very early intervention by 3 months of age.

Keywords: hearing loss; language development; EHDI

Acronyms: BEPTA = better ear pure tone average; CASL = Comprehensive Assessment of Spoken Language; CELF-4 = Clinical Evaluation of Language Fundamentals, 4th ed.; EHDI = Early Hearing Detection and Intervention; EI = early intervention; HA = hearing aid; HL = hearing loss; NH = normal hearing; NHS = Newborn Hearing Screening; OCHL = Outcomes of Children with Hearing Loss, PPVT-4 = Peabody Picture Vocabulary Test, 4th ed.; PTA = pure tone average; WASI-II = Wechsler Abbreviated Scale of Intelligence

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Hearing loss (HL) in childhood is a common condition, with a prevalence around 3 per 1000 births (Mehra et al., 2009). Children with HL are at risk for significant communication delays (Tomblin, Harrison et al., 2015). Reduced access to linguistic input limits children with HL from achieving their full developmental potential (Meinzen-Derr et al., 2018; Moeller & Tomblin, 2015). With the advent of universal newborn hearing screenings, a majority of children with HL in the United States are meeting one or more of the Early Hearing Detection and Intervention (EHDI) goals of screening by 1 month of age, HL confirmation by 3 months, and entry into early intervention by 6 months (Holte et al., 2012; Walker et al., 2014; Walker et al., 2017). Meeting these benchmarks has a positive impact on language, psychosocial, and academic outcomes for children with HL (Joint Committee on Infant Hearing [JCIH], 2019).

Because early intervention facilitates the acquisition of age-appropriate language skills (Moeller, 2000; Pimperton & Kennedy, 2012; Sininger et al., 2010; Watkin et al., 2007; Yoshinaga-Itano et al., 1998; Yoshinaga-Itano et al., 2017), researchers and clinicians have debated whether to pursue more aggressive milestones for EHDI services, referred to as the “1-2-3” benchmarks: screening by 1 month, confirmation by 2 months, entry into early intervention by 3 months. In the 2019 JCIH position statement, the committee recommended that U.S. states who currently are meeting 1-3-6 benchmarks should strive toward accomplishing 1-2-3 benchmarks. However, there is currently little direct evidence to suggest that reaching benchmarks earlier would result in further improvements in outcomes compared to the current 1-3-6 benchmarks. Documenting the potential effects of very early intervention has important public health significance and would provide empirical evidence to guide best-practice models for children with HL for physicians, audiologists, parents, and other stakeholders. It is critical to have these data before we can encourage states to devote the time and resources needed to implement an accelerated EHDI timeline.

Historically, prospective and longitudinal cohorts of children with HL who experienced early identification and intervention have not been available to study. Thus, the field of audiology has not had the opportunity to study the effects of accelerated EHDI timelines on language growth in children with HL compared to the traditional 1-3-6 recommendations. It is critical to address these questions about earlier intervention because evidence suggests that children with HL, including those with mild HL, remain at risk for language delays even in an era of newborn hearing screening (Walker et al., 2020; Yoshinaga-Itano et al., 2017).

The primary goal of the current study is to estimate the language growth trajectories for children with mild to severe bilateral HL and to compare the growth rates for children who met the traditional 1-3-6 benchmarks versus the growth rates for children who met an accelerated 1-2-3 timeline with peers with normal hearing (NH). In these analyses, we examined growth of vocabulary (i.e., the content of language or word knowledge), grammar (i.e., the structural form of language or morphosyntactic knowledge), and global language (i.e., a combination of receptive and expressive language). A secondary goal was to examine the effects of HL severity and socio-economic status (SES) on growth trajectories for children in EI. We compared prospective longitudinal data in children who had cognitive skills within normal limits, no additional disabilities, and used spoken English. The current study rectifies some of the previous issues with investigations of treatment effects of EHDI. Specifically, we had a unique opportunity to examine prospective longitudinal data in children with HL or NH who have cognitive skills within or above normal limits, no major secondary disabilities, and were from monolingual English-speaking homes. Thus, the findings from this study provide us with an opportunity to address questions about timing of intervention without many of the additional confounds that are typical in this line of research (Ching et al., 2017; Ching et al., 2013).

In both aims, our interest is in language growth rates for children with HL from 6 months to 8 years of age. Due to this wide age range we needed to use developmentally appropriate measures; thus, different measurement instruments were used over time. Ideally, the measurement of growth employs a common scale across time that reflects a common trait. Our previous reports of language growth analysis used standard scores provided by norm-referenced tests to address the challenge of a common scale across time (Tomblin, Harrison et al., 2015). Using standard scores placed all measures on the same scale but did not control for systematic differences in the norm-referenced groups. True changes in growth were confounded with changes in the ability levels of the norm-referenced groups. Further, the scaling of standard scores did not reflect the expected absolute gains in language ability over development, but instead indexed relative growth. Children with average growth were expected to have the same standard score across time. In this report, we have adopted a novel method for measuring language growth that draws on Bayesian methods to estimate a latent language ability based on the raw scores produced by our tests (Ward et al., 2020). Compared to traditional frequentist approaches, the Bayesian methods are valuable as they allow information to be borrowed across multiple tests of the same latent construct. The Bayesian model employed in the current study uses all available data to construct latent growth curves; thus, the statistical analysis did not require that children have the same measurements at every test visit.

**Method**

**Participants**

The Outcomes of Children with Hearing Loss (OCHL) study used an accelerated longitudinal design. We recruited children between 6 months and 7 years at enrollment into the study. They were followed beginning at time of enrollment biannually from 6 months to 2 years, and annually from 2 to 8 years (Holte et al., 2012; Tomblin, Walker, et al., 2015). Table 1 provides a summary of the participants’ demographic and audiologic characteristics.
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Table 1
Demographic and Audiologic Characteristics for Children with Hearing Loss who met 1-2-3 Benchmarks or 1-3-6 Benchmarks and Children with Normal Hearing (CNH)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>1–2–3 (n = 60)</th>
<th>1–3–6 (n = 73)</th>
<th>CNH (n = 116)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Percentage of Members</td>
<td>Percentage of Members</td>
<td>Percentage of Members</td>
</tr>
<tr>
<td>Sex, male</td>
<td>48% (29/60)</td>
<td>60% (44/73)</td>
<td>47% (54/116)</td>
</tr>
<tr>
<td>Race</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>87% (52/60)</td>
<td>79% (58/73)</td>
<td>79% (92/116)</td>
</tr>
<tr>
<td>Black</td>
<td>3% (2/60)</td>
<td>8% (6/73)</td>
<td>6% (7/116)</td>
</tr>
<tr>
<td>Asian</td>
<td>2% (1/60)</td>
<td>3% (2/73)</td>
<td>2% (2/116)</td>
</tr>
<tr>
<td>Other</td>
<td>8% (5/60)</td>
<td>10% (7/73)</td>
<td>13% (15/116)</td>
</tr>
<tr>
<td>Receive private insurance</td>
<td>80% (48/60)</td>
<td>75% (55/73)</td>
<td>78% (87/112)</td>
</tr>
<tr>
<td>Full-term birth (&gt; 36 weeks)</td>
<td>88% (52/59)</td>
<td>77% (56/73)</td>
<td>86% (90/105)</td>
</tr>
<tr>
<td>Maternal education level</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High school or less</td>
<td>10% (6/60)</td>
<td>17% (12/71)</td>
<td>19% (21/108)</td>
</tr>
<tr>
<td>Some college</td>
<td>28% (17/60)</td>
<td>28% (20/71)</td>
<td>14% (15/108)</td>
</tr>
<tr>
<td>Bachelor’s degree</td>
<td>30% (18/60)</td>
<td>30% (21/71)</td>
<td>32% (35/108)</td>
</tr>
<tr>
<td>Post-graduate education</td>
<td>32% (19/60)</td>
<td>25% (18/71)</td>
<td>34% (37/108)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Mean</th>
<th>SD</th>
<th>Mean</th>
<th>SD</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Better-ear pure tone average (dB HL)</td>
<td>49.80</td>
<td>13.20</td>
<td>50.06</td>
<td>12.97</td>
<td>N/A</td>
</tr>
<tr>
<td>Age at first hearing evaluation (months)</td>
<td>1.21</td>
<td>0.55</td>
<td>2.53</td>
<td>1.25</td>
<td>N/A</td>
</tr>
<tr>
<td>Age at confirmation (months)</td>
<td>1.56</td>
<td>0.74</td>
<td>3.21</td>
<td>1.42</td>
<td>N/A</td>
</tr>
<tr>
<td>Age at hearing aid fitting (months)</td>
<td>3.05</td>
<td>1.46</td>
<td>5.72</td>
<td>4.64</td>
<td>N/A</td>
</tr>
<tr>
<td>Age at entry into early intervention (months)</td>
<td>2.30</td>
<td>0.76</td>
<td>4.59</td>
<td>1.18</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Note. HL = hearing loss.
1Insurance status not reported for 4 CNH.
2Pregnancy length not reported for 1 child in the 1-2-3 group and 11 CNH.
3Maternal education level not reported for 2 children in 1-3-6 group and 8 CNH.

The full cohort consisted of 317 children with HL. Inclusion criteria were (a) permanent, bilateral, better-ear 4-frequency pure-tone average (BEPTA) of 20 to 75 dB HL, (b) at least one primary caregiver who used spoken English, and (c) no known additional sensory or neurodevelopmental disorders. Children who used sign language as their primary communication mode were excluded because inclusion would require a different approach to language outcome measurement, making it difficult to compare groups.

Within the cohort, 78 passed their Newborn Hearing Screening (NHS) or did not receive an NHS; these children were excluded from these analyses due to the inability to document whether the HL was congenital. Two hundred thirty-nine failed their NHS: 25% (n = 60) met 1-2-3 benchmarks, 31% (n = 73) met 1-3-6 benchmarks, and 44% (n = 106) had a delay in diagnosis or EI. Data from the 106 children who were delayed in diagnosis or EI have been examined in previous analyses and are excluded from the current study (Tomblin, Harrison, et al., 2015). In the current study, we examined the 133 children enrolled in EI by 3 or 6 months, to directly test the effect of a 1-2-3 timeline relative to the current JCIH 1-3-6 recommendations. Inclusion in the 1-2-3 group was defined as NHS by 1 month, diagnostic testing by 2 months, and EI by 3 months. Children in the 1-3-6 group had NHS by 1 month, diagnostic testing between 3 and 5 months, and EI between 3 and 6 months. All children were fitted with hearing aids. Children in the 1-2-3 group were fitted at an average age of 3.05 months (SD = 1.46) and wore their hearing aids an average of 10.33 hours per day across visits (SD = 3.24). Children in the 1-3-6 group were fitted at an average age of 5.72 months (SD = 4.64) and wore their hearing aids an average of 10.59 hours per day across visits (SD = 3.03). There was no significant difference in hearing aid use time between the two groups (p = .38). Ten percent (n = 6/60) and 11% (n = 8/73) of the 1-2-3 and 1-3-6 groups, respectively, presented with a progressive HL (defined as more than a 10 dB HL increase in PTA between visits). Because the number of children who demonstrated progressive HL in either group was small, we did not control for progression of hearing loss in the statistical analyses.

One hundred sixteen children with NH, matched by age and maternal education level (as a proxy for SES) with the
children with HL, also participated in the OCHL study. The children with NH were included to provide a comparison group that was well matched with the children with HL in terms of home and family background. Children with NH used spoken English to communicate. Nonverbal cognition in both children with HL and children with NH was average to above-average, as measured by nonverbal subtests of the Wechsler Preschool and Primary Scale of Intelligence-III (Wechsler, 2002) at age 4 years or Wechsler Abbreviated Scale of Intelligence-2 (WASI-2; Wechsler & Hsiao-pin, 2011) at age 6 years.

**Procedures**

All study procedures were approved by Institutional Review Boards at the University of Iowa, Boys Town National Research Hospital, and the University of North Carolina.

**Hearing and Language Measures**

Parents completed an intake questionnaire that documented age at NHS, HL confirmation, hearing aid (HA) fitting, and EI. Clinically certified audiologists who were experienced in working with children completed hearing assessments at each visit, including air-conduction and bone-conduction thresholds at 500, 1000, 2000, and 4000 Hz at a minimum. The BEPTA at these four frequencies was calculated for subsequent analyses.

The language test battery consisted of a combination of parent-report measures and standardized, norm-referenced tests. The language examiners included audiologists, clinically certified speech-language pathologists, or licensed teachers. The measures varied depending on the chronological age of the children. The Vineland Adaptive Behavior Scales-2 Parent/Caregiver Form (Sparrow et al., 2005) was administered between 6 and 48 months of age. For the current analysis we only included the Vineland Receptive and Expressive language subscales. At ages 3, 4, 6, and 8 years we administered the Comprehensive Assessment of Spoken Language (CASL; Carrow-Woolfolk, 1999). Scores on the Basic Concepts subtest (vocabulary) and the Grammar Construction (grammar) are included in the current analysis. The Clinical Evaluation of Language Fundamentals-4 (CELF-4; Semel et al., 2004) Word Structure subtest, which assesses grammar, was administered at 5 and 7 years of age. The Peabody Picture Vocabulary Test-4 (PPVT-4; Dunn & Dunn, 2007) was administered at 5 and 7 years of age, and the WASI-2 Vocabulary subtest (Wechsler & Hsiao-pin, 2011) was administered at 7 and 8 years of age. Both tests measure vocabulary knowledge. Table 2 displays the constructs, test names, descriptions, types of scores, and the ages at which the language assessments were administered.

**Table 2**

<table>
<thead>
<tr>
<th>Construct/test name</th>
<th>Description</th>
<th>Score</th>
<th>Visit Administered</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global Language</td>
<td></td>
<td>Raw score</td>
<td>12m 18m 2yr 3yr 4yr 5yr 6yr 7yr 8yr</td>
</tr>
<tr>
<td>VABS-2 Expressive Language and Receptive Language</td>
<td>Parent-report checklist</td>
<td>X X X X X X</td>
<td></td>
</tr>
<tr>
<td>Grammar</td>
<td></td>
<td>Raw score</td>
<td>X X X X X</td>
</tr>
<tr>
<td>CASL Syntax Construction</td>
<td>Expressive morphosyntax; cloze procedure with picture support</td>
<td>X X X X X X</td>
<td></td>
</tr>
<tr>
<td>CELF-4 Word Structure</td>
<td>Expressive morphosyntax; cloze procedure with picture support</td>
<td>X X</td>
<td></td>
</tr>
<tr>
<td>Vocabulary</td>
<td></td>
<td>Raw score</td>
<td>X X</td>
</tr>
<tr>
<td>CASL Basic Concepts</td>
<td>Lexical/semantic knowledge; picture pointing task with four-item closed set</td>
<td>X X</td>
<td></td>
</tr>
<tr>
<td>PPVT-4</td>
<td>Receptive vocabulary; picture pointing task with four-item closed set</td>
<td>X X</td>
<td></td>
</tr>
<tr>
<td>WASI-2 Vocabulary</td>
<td>Expressive vocabulary; definitions</td>
<td>X X</td>
<td></td>
</tr>
</tbody>
</table>

*Note. VABS-2 = Vineland Adaptive Behavior Scales; CASL = Comprehensive Assessment of Spoken Language; CELF-4 = Clinical Evaluation of Language Fundamentals; PPVT-4 = Peabody Picture Vocabulary Test; WASI-2 = Wechsler Abbreviated Scale of Intelligence.*
Children were followed for an average of 1.8 years, and throughout follow-up were measured between two and 13 times across all instruments, with 50% of the children having between 8 and 10 measurements. Most children (53.6%) were measured on four instruments and 21.8% were measured on all seven instruments.

Statistical Analysis

We constructed latent growth curve models of three constructs: global language (Vineland Receptive and Expressive subscales), grammar (CASL Syntax Construction, CELF-4 Word Structure), and vocabulary (CASL Basic Concepts, PPVT-4, WASI-2 Vocabularly) in the Bayesian paradigm. For this analysis, the Bayesian paradigm is preferred because it provides an intuitive framework for estimation, dividing a complex process into a series of smaller, well-defined components using conditional probability (Oleson et al., 2019). Compared to Frequentist implementation, the Bayesian framework is advantageous as it allows information to be borrowed across multiple tests of the same latent construct. Children did not always have measurements on every test or multiple measurements on a test over time, and the Bayesian model leveraged all available data to construct latent growth curves.

Bayesian hierarchical models can be broken down into three components. The data model describes the distribution of the observed data, the process model describes the scientific process for the parameters of the data’s distribution, and the parameter model sets the remaining prior distributions in the hierarchical model (Cressie & Wikle, 2015). These three components are combined using Bayes’ rule to give the posterior distribution, which defines the probability distribution of the parameter values conditioned on any prior scientific evidence in the parameter model and the observed data in the data model. Another advantage of the Bayesian paradigm is in the natural and intuitive interpretation given by the posterior distribution.

For the data model of each of the three constructs, we assume that the individual score on each associated test over time is approximately normally distributed with its own mean and variance parameters. The process model defines the mean for each score over time using a linear equation which allows for group- and subject-specific intercepts and slopes. Time was scaled so that the intercept occurred at 6 months for interpretability. Information across multiple tests in each construct was combined by including effects for each measure in the intercept and slope and constraining the effects to sum to zero for identifiability. The subject-specific effects account for the within-subject correlation and borrow strength across each language measure. Each model controlled for HL severity and maternal education level. These two factors were included because they could influence the timing of hearing aid fitting and we wanted to control these effects. We treated HL severity as a continuous measure; children with NH were given a HL severity value of zero, corresponding to no HL. We treated maternal education level as an ordinal variable with four levels: (a) high school or less, (b) some college, (c) bachelor’s degree, or (d) post-graduate education. Severity of HL and maternal education were included as covariates in the intercept terms, meaning the effects of these variables were held constant over time.

The final stage of the hierarchical model is to assign prior distributions for all the remaining parameters. We used vague but proper priors. The test effects were given Normal priors with mean 0 and large, uninformative standard deviation of 10,000. The group effects were also given Normal priors with mean 0 and a large uninformative standard deviation of 1,000. The random subject effects were given a multivariate normal distribution with mean 0 and variance-covariance matrix which followed an inverse Wishart distribution. All remaining variance parameters were given non-informative inverse gamma (0.1, 0.1) priors. The vague priors reflect the lack of preexisting information on the parameters and ensures data driven final outcomes.

To compare growth curves for each language construct, we analyzed the posterior distributions of the differences in the intercept and slope between each of the three groups: children with NH, children with HL who met the 1-3-6 benchmark, and children with HL who met the 1-2-3 benchmark. The posterior mean of each difference provides an estimate of the average difference in the intercept or slope, given the observed data. We used Bayesian credible intervals (CI) to test for significant differences: A 95% CI defines the region where the true difference in intercepts or slopes lies with 95% probability, given the data. A 95% CI for the difference in intercepts or slopes that does not include zero indicates a statistically significant difference in that parameter between the groups at the 5% level. Analyses were performed with R version 4.0.2 and OpenBUGS version 3.2.3 (Lunn et al., 2000). For each model, three chains were run for 30,000 iterations after a burn-in period, with convergence indicated by all parameters achieving a Gelman-Rubin statistic less than 1.1 (Gelman & Rubin, 1992).

Results

Table 3 summarizes the posterior distribution of the group differences in the intercept and slope and covariate effects for each language construct model (global language, grammar, and vocabulary). The posterior means of the group differences in the intercepts and slopes represent the average difference in the latent score at six months and the average difference in yearly growth of the latent score, respectively. Significant credible intervals are shaded.

Children who Met 1-3-6 Benchmarks Compared to Children with Normal Hearing

Figure 1A displays growth trajectories of the 1-3-6 group compared to children with NH for each language construct. Across all three language constructs, there was no difference in intercepts or slopes between the 1-3-6 and NH groups. These results indicate that children with HL that met 1-3-6 benchmarks and children with NH had similar starting points and growth trajectories in global language, grammar, and vocabulary.
Table 3

Posterior Mean, Standard Deviation, and 95% Credible Intervals (CI) for Each Parameter of Interest

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Global Language</th>
<th>Grammar</th>
<th>Vocabulary</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Group</td>
<td>n</td>
<td>Group</td>
</tr>
<tr>
<td>NH</td>
<td>NH</td>
<td>82</td>
<td>NH</td>
</tr>
<tr>
<td>1–2–3</td>
<td>1–2–3</td>
<td>51</td>
<td>1–2–3</td>
</tr>
<tr>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>Intercept (6 months)</td>
<td>-2.43 (2.09)</td>
<td>-2.05 (2.30)</td>
<td>-2.88 (3.02)</td>
</tr>
<tr>
<td>Slope</td>
<td>0.67 (0.63)</td>
<td>0.32 (0.44)</td>
<td>0.52 (0.58)</td>
</tr>
<tr>
<td>Intercept (6 months)</td>
<td>-3.58 (2.08)</td>
<td>-3.54 (2.37)</td>
<td>-2.49 (3.19)</td>
</tr>
<tr>
<td>Slope</td>
<td>1.64 (0.64)</td>
<td>1.01 (0.48)</td>
<td>0.77 (0.60)</td>
</tr>
<tr>
<td>Intercept (6 months)</td>
<td>1.14 (1.48)</td>
<td>1.49 (1.92)</td>
<td>-0.39 (2.64)</td>
</tr>
<tr>
<td>Slope</td>
<td>-0.97 (0.65)</td>
<td>-0.69 (0.54)</td>
<td>-0.26 (0.66)</td>
</tr>
<tr>
<td>Severity of Hearing Loss</td>
<td>-0.07 (0.03)</td>
<td>-0.04 (0.03)</td>
<td>-0.06 (0.04)</td>
</tr>
<tr>
<td>Maternal Education</td>
<td>1.31 (0.36)</td>
<td>2.28 (0.38)</td>
<td>2.86 (0.45)</td>
</tr>
</tbody>
</table>

Note. A 95% Credible Interval (CI) for the difference in intercepts or slopes that does not include zero indicates a statistically significant difference in that parameter between the groups at the 5% level. Shaded CIs indicate significant differences. NH = normal hearing.

Children who Met 1-2-3 Benchmarks Compared to Children with Normal Hearing

Figure 1B displays growth trajectories of the 1-2-3 group compared to children with NH. The intercept for the 1-2-3 group was not significantly different than the intercept for children with NH for any language construct. The slope for the 1-2-3 group was significantly higher than the slope for the NH group in the global language and grammar models, indicating children who met 1-2-3 benchmarks had steeper growth in global language and grammar than their hearing peers. Children in the 1-2-3 group did not significantly differ from children with NH in vocabulary growth.

Children who Met 1-2-3 Benchmarks Compared to Children who met 1-3-6 Benchmarks

Figure 1C displays the growth trajectories of the 1-2-3 versus 1-3-6 group. There was no difference in intercepts or slopes between the groups on any language construct. These results indicate that the two groups of children with HL had similar starting points in global language, grammar, and vocabulary. They also indicate that the two groups demonstrated similar language growth trajectories in these three constructs.

Outcomes by HL Severity and Maternal Education Level

HL severity was significant in the global language model; more severe HL was associated with a reduction in a child’s global language score, regardless of whether they met 1-2-3 or 1-3-6 benchmarks. HL severity was not significant in the grammar or vocabulary models. This lack of significance suggests that any degree of HL impacts grammar or vocabulary development. Maternal education level was significant in all three models. Regardless of group or language construct, as maternal education level increased, language scores were higher overall. This effect remained constant over time.

Discussion

This paper is among the first to prospectively follow a well-described cohort of children with HL who have met 1-2-3 benchmarks or 1-3-6 benchmarks, using a comprehensive battery of parent-report and direct language assessments out to age 8 years. With this cohort, we were able to compare initial language abilities and longitudinal growth trajectories between these two groups, as well as relative to an age- and SES-matched group of children with NH. A major strength of our study is the Bayesian approach to longitudinal analysis, which allowed us to estimate...
Figure 1
Population Curves and 95% Credible Intervals Over Time

A 1–3–6 vs NH
Global Language
Grammar
Vocabulary

B 1–2–3 vs NH
Global Language
Grammar
Vocabulary

C 1–3–6 vs 1–2–3
Global Language
Grammar
Vocabulary

Note. Group population curves and 95% credible intervals for global language (left), grammar (center), and vocabulary (right) constructs.
latent language traits using different tests and scales across a wide age range. The primary advantage to this approach was that we could avoid problems with measuring language growth using standard scores from norm-referenced tests. This also allowed us to avoid floor or ceiling effects because the test measures were developmentally appropriate at every visit.

Results indicate that children with mild to severe HL who are enrolled in EI by 6 months develop language skills that are on par with their hearing peers. Although this trend is seen in vocabulary for both groups, the children who met the 1-2-3 benchmarks had the additional advantage of showing steeper growth trajectories in global language and grammar compared to children with NH. The children who met the 1-3-6 benchmarks did not show a difference in growth trajectories for these constructs compared to the NH group.

Our findings of a positive effect of EI by 3 or 6 months of age is consistent with other cross-sectional reports. An Australian study compared global language scores for children with moderate to profound HL who received HAs by 3 or 6 months to children who were fit later (Ching et al., 2017). Although they did not specify if children were enrolled in EI at these ages, results indicated that earlier HA fitting led to better language outcomes at age 5, relative to later HA fitting. Further, children with moderate HL who were fitted with HAs by 3 or 6 months showed language scores within the average range for norm-referenced tests (Ching & Leigh, 2020).

Similarly, Yoshinaga-Itano et al. (2017) examined expressive vocabulary outcomes in a cross-sectional sample of 448 children with bilateral mild to profound HL. They found that children who met the 1-3-6 JCIH benchmarks had better vocabulary outcomes than children who experienced delays in diagnosis or early intervention, as measured by the parent-report MacArthur-Bates Communicative Development Inventories. These previous cross-sectional studies support the finding in this study that earlier ages of identification can positively impact global language abilities in children with HL.

The finding of steeper growth in global language and grammar for the 1-2-3 group than children with NH provides evidence that reaching intervention benchmarks at younger ages can result in improved outcomes. Specific to grammar, this finding is consistent with previous research indicating that structural aspects of language (i.e., form) may be a particularly challenging aspect of development for children with mild to severe HL (Tomblin, Harrison et al., 2015; Walker et al., 2020). Form is an especially vulnerable area of language for children with HL because it depends on the processing of fine phonetic details, which are difficult to perceive in the presence of degraded language input. Children enrolled in earlier intervention may experience a multitude of benefits including earlier family access to treatment, HA support, and informational counseling that protect against differential risk in grammar. The positive impact of these benefits is substantiated in the growth trajectories in grammar and global language for the children who received EI by 3 months.

In contrast to the grammar and global language measures, vocabulary growth trajectories did not show differences across groups. This finding may be because lexical measures, particularly assessments of vocabulary breadth, are protected by higher level factors such as contextual cues and redundancy in linguistic input (Moeller et al., 2015; Walker et al., 2019). As a result, the content domain (i.e., vocabulary) is less sensitive to the impact of cumulative auditory experience than structural aspects of language (i.e., morphosyntax).

Implementation of the 1-3-6 benchmarks for children with HL remains challenging. Forty-four percent of our full cohort did not meet all three benchmarks, a proportion that is similar to other studies (Yoshinaga-Itano et al., 2017). The lack of success in meeting diagnostic or EI benchmarks raises questions about whether implementing more stringent benchmarks would have an appreciable impact on language outcomes in children with HL. This analysis indicates that a subsample of children with HL were able to meet the 1-2-3 benchmarks, and there were benefits to language growth in global language and grammar. Setting earlier benchmarks for EI may decrease the number of children who meet the benchmarks, but it would also send a message that EI should proceed as quickly as possible to promote opportunities for language development.

Limitations

Although this study is one of the first to contrast outcomes between children who met the current 1-3-6 benchmarks for early intervention with children who met an earlier 1-2-3 criterion, there are several important limitations that must be considered. The study sample was relatively homogeneous compared to groups of children with HL in previous studies or the general population. The sample included only children from English-speaking homes without additional disabilities. It should be noted that clinical caseloads are rarely this homogenous: Approximately 40% of children with HL have an additional disability and around 50% are from a culturally or linguistically diverse population (Gallaudet Research Institute, 2003). Further, the participants all had bilateral hearing loss in the mild to severe range. The exclusion of children with profound HL allowed us to control for the effects of device type (i.e., all children wore HAs; no children had cochlear implants) and communication mode (all children relied entirely on spoken English), but limited investigations of the full range of hearing levels. This is an ideal cohort for examining the effects of HL and EI on language outcomes with minimal confounds, but these results likely overestimate outcomes from more diverse populations.

Conclusions

This study documents the positive impact of early diagnosis and intervention of HL on language outcomes in children with congenital HL. Children who received EI by 6 months of age were able to maintain language growth at a level commensurate to hearing peers. These parallel growth trajectories were evident in vocabulary for children who met the recommended 1-3-6 benchmarks as well as the accelerated 1-2-3 benchmarks. However, children who
met 1-2-3 demonstrated steeper growth in global language and grammar relative to the NH group. These findings provide preliminary evidence to support the potential effects of very early intervention in children with HL, but additional data are needed before we can encourage states to devote the time and resources needed to implement an accelerated EHDI timeline.

References


