1 Characterizing North Carolina's Deaf/Hard-of-Hearing Infants and Toddlers: Predictors of

2 Vocabulary, Diagnosis, and Intervention

3 Erin Campbell[1] & Elika Bergelson[1]

4 [1] Duke University

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Introduction

In the United States, 1-2 children are born with hearing loss, per 1,000 births (CDC, 2018). This translates to 114,000 Deaf or Hard of Hearing (DHH) children born in the U.S. per year (Martin, Hamilton, Osterman, & Driscoll, 2019). Of these 114,000, ~90% will be born to hearing parents (Mitchell & Karchmer, 2004), in a home where spoken language is likely the dominant communication method. Depending on the type and degree of hearing loss and whether the child uses amplification, spoken linguistic input will be partially or totally inaccessible. Some of these children will develop spoken language proficiency within the range of their hearing peers (Geers, Mitchell, Warner-Czyz, Wang, & Eisenberg, 2017; Verhaert, Willems, Van Kerschaver, & Desloovere, 2008), but many will face persistent spoken language deficits (Eisenberg, 2007; Luckner & Cooke, 2010; Moeller, Tomblin, Yoshinaga-Itano, Connor, & Jerger, 2007; Sarchet et al., 2014), which may later affect reading ability (Kyle & Harris, 2010) and academic achievement (Karchmer & Mitchell, 2003; Qi & Mitchell, 2012).

Despite many excellent studies examining language development in DHH children, there is still a gap in the literature describing and analyzing spoken language development across the full range of children receiving services for hearing loss, with many studies focusing in on specific subgroups (e.g. children under age X with Y level of hearing loss and Z amplification approach, e.g. Vohr et al., 2008; Yoshinaga-Itano, Sedey, Wiggin, & Mason, 2018). In what follows, we first summarize the previous literature on predictors of spoken language outcomes in DHH children. We then provide a brief overview of a common vocabulary measure used in the current study, the MacArthur-Bates Communicative Development Inventory (CDI). Finally, we turn to an empirical analysis of early vocabulary in a wide range of young children receiving state services in North Carolina. We have two

broad goals in what follows. First, we aim to provide a comprehensive description of a heterogeneous group of young children who receive state services for hearing loss. Second, we aim to connect the intervention approaches and child characteristics of this sample with children's spoken vocabulary[1], with the broader goal of considering the success of early diagnosis and intervention initiatives.

Predictors of Language Outcomes

Though the literature points towards spoken language delays and deficits for DHH children, this is a highly variable population with highly variable outcomes (Pisoni, Kronenberger, Harris, & Moberly, 2018). Previous research indicates that gender (Ching et al., 2013; Kiese-Himmel & Ohlwein, 2002), additional disability (Ching et al., 2013; Verhaert et al., 2008; Yoshinaga-Itano, Sedey, Wiggin, & Chung, 2017), degree and configuration of hearing loss (Ching et al., 2013; de Diego-Lázaro, Restrepo, Sedey, & Yoshinaga-Itano, 2018; Vohr et al., 2011; Yoshinaga-Itano et al., 2017), amplification (Walker et al., 2015), communication (Geers et al., 2017), and early diagnosis/intervention (Yoshinaga-Itano et al., 2017, 2018) predict language outcomes in DHH children. We first provide a brief literature review on the effect of these predictors on language skills in DHH children.

Gender. For hearing children, the literature points to a female gender advantage in early language acquisition. Girls speak their first word earlier (Macoby, 1966), have a larger (Bornstein, Hahn, & Haynes, 2004; Fenson et al., 1994; Frank, Braginsky, Yurovsky, & Marchman, 2017) and faster-growing vocabulary (Huttenlocher, Haight, Bryk, Seltzer, & Lyons, 1991), and stronger grammatical and phonological skills (Lange, Euler, & Zaretsky,

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[1] Despite exciting, increasing, and converging evidence for benefits of early sign language exposure (e.g., Clark et al., 2016, Davidson et al., 2014; Hrastinski & Wilbur, 2016; Magnuson, 2000; Schick et al., 2007; Spencer, 1993), the majority of DHH children will not be raised in a sign language environment. This is particularly true for North Carolina, which does not have a large community of sign language users, relative to states like Maryland or areas like Washington D.C. or Rochester, NY. For this reason, and because no families in our sample used a full-fledged signed language, we focus on spoken language development.

2016; Özçalışkan & Goldin-Meadow, 2010). This finding appears to be consistent across

studies (Wallentin, 2009), various spoken languages (Frank, Braginsky, Marchman, &

Yurovsky, 2019), and gesture (Özçalışkan & Goldin-Meadow, 2010).

The DHH literature presents a more mixed (though rather understudied) picture. On

one hand, DHH girls, like hearing girls, have been found to have a larger spoken vocabulary

than DHH boys (Ching et al., 2013; Kiese-Himmel & Ohlwein, 2002). However, in contrast

to their hearing peers, DHH children do not seem to show a gender-based difference for some

aspects of syntactic development (Pahlavannezhad & Tayarani Niknezhad, 2014).

Comorbidities.   Additional co-morbid disabilities occur frequently in the DHH

population, perhaps as much as three times more than in the hearing population (Pollack,

1997). Incidence estimates for co-occurring disabilities in DHH children range from 25-51%

(Bruce & Borders, 2015; Guardino, 2008; Holden-Pitt & Diaz, 1998; Luckner & Carter, 2001;

Picard, 2004; Schildroth & Hotto, 1996; Soukup & Feinstein, 2007), with approximately 8%

of DHH children living with 2 or more co-occurring disabilities (Schildroth & Hotto, 1996).

Some of these conditions, particularly those which carry risk of developmental delay

(e.g., Down syndrome), result in language delays independent of hearing loss (Chapman,

1997; Kristoffersen, 2008; Weismer, Lord, & Esler, 2010). These effects vary by the nature of

the specific disability (Cupples et al., 2014, 2018), with cognitive ability more predictive of

language outcomes than presence or absence of additional disability (Meinzen-Derr, Wiley,

Grether, & Choo, 2011; Sarant, Holt, Dowell, Richards, & Blamey, 2008). Disability and

hearing loss likely each contribute to a given child's spoken language development (Ching et

al., 2013; Rajput, Brown, & Bamiou, 2003; Van Nierop et al., 2016), with differential effects

of each (Vesseur et al., 2016). In some cases, additional disabilities appear to interact with

hearing loss to intensify developmental delays (Birman, Elliott, & Gibson, 2012; Pierson et

al., 2007).

Furthermore, incidence of hearing loss is higher among children born premature

78 (defined as < 37 weeks gestational age). Compared to an incidence of 0.2% in full-term

79 infants, incidence of hearing loss in extremely premature infants (defined as < 33 weeks

80 gestational age) ranges 2–11%, with increased prematurity associated with increased rates of

81 hearing loss (Wroblewska-Seniuk, Greczka, Dabrowski, Szyfter-Harris, & Mazela, 2017).

82   Independently of hearing status, prematurity is linked to increased risk of language

83 delay and disorder (Barre, Morgan, Doyle, & Anderson, 2011; Carter & Msall, 2017; Cusson,

84 2003; Rechia, Oliveira, Crestani, Biaggio, & de Souza, 2016; Van Noort-van Der Spek,

85 Franken, & Weisglas-Kuperus, 2012; Vohr, 2014). Unfortunately, research on language

86 development in premature DHH children is scant (Vohr, 2016), so it remains unclear how

87 hearing loss and prematurity may interact within spoken language skills. One study of

88 premature infants finds that auditory brainstem response during newborn hearing screening

89 predicts language performance on the PLS-4 at age 3 (Amin, Vogler-Elias, Orlando, & Wang,

90 2014), suggesting a link between prematurity, hearing loss, and language development in

91 early childhood, though further research is needed in this domain. In extremely premature

92 DHH children, incidence of additional disabilities may be as high as 73% (Robertson,

93 Howarth, Bork, & Dinu, 2009). Indeed, pre-term infants with comorbidities have been found

94 to be more likely to also have hearing loss than those without comorbidities (Schmidt et al.,

95 2003), further complicating language development for this population.

96   **Audiological Characteristics.**   Hearing loss varies in severity, ranging from slight

97 to profound (Clark, 1981). More severe hearing loss (less access to spoken language)

98 typically results in more difficulty with spoken language in infancy (Vohr et al., 2008), early

99 childhood (Ching et al., 2010, 2013; Sarant et al., 2008; Sininger, Grimes, & Christensen,

100 2010; Tomblin et al., 2015) and school-age children (Wake, Hughes, Poulakis, Collins, &

101 Rickards, 2004). Although profound hearing loss is associated with more pronounced spoken

102 language difficulty, even mild to moderate hearing loss is associated with elevated risk of

103 language disorders (Blair, Peterson, & Viehweg, 1985; Delage & Tuller, 2007).

104   Hearing loss also varies in whether it affects one ear or both. Bilateral hearing assists

105 speech perception, sound localization, and loudness perception in quiet and noisy

106 environments (Ching, Van Wanrooy, & Dillon, 2007). The literature on hearing aids and

107 cochlear implants also points to benefits for bilateral auditory input (Lovett, Kitterick,

108 Hewitt, & Summerfield, 2010; Sarant, Harris, Bennet, & Bant, 2014; Smulders et al., 2016).

109 At school-age, 3–6% of children have unilateral hearing loss (Ross, Visser, Holstrum, Qin, &

110 Kenneson, 2010). Although children with unilateral hearing loss have one "good ear," even

111 mild unilateral hearing loss has been tied to higher risk of language delays and educational

112 challenges relative to hearing children (Kiese-Himmel, 2002; Lieu, 2004, 2013; Lieu,

113 Tye-Murray, & Fu, 2012; Vila & Lieu, 2015). Just as in the bilateral case, more severe

114 hearing loss leads to greater deficits in spoken language and educational outcomes for

115 children with unilateral hearing loss (Anne, Lieu, & Cohen, 2017; Lieu, 2013).

116   Many DHH children receive hearing aids (HAs) or cochlear implants (CIs) to boost

117 access to the aural world. These devices have been associated with better speech perception

118 and spoken language outcomes (Niparko et al., 2010; Walker et al., 2015; Waltzman et al.,

119 1997). In turn, aided audibility predicts lexical abilities in children with HAs (Stiles, Bentler,

120 & McGregor, 2012).

121   For both hearing aids and cochlear implants, earlier fit leads to better spoken language

122 skills, if the amplification is effective. For hearing aids, some studies find that children with

123 milder hearing loss who receive hearing aids earlier have better early language achievement

124 than children who are fit with hearing aids later (Tomblin et al., 2015), but this finding does

125 not hold for children with severe-to-profound hearing loss (Kiese-Himmel, 2002; Watkin et

126 al., 2007) (for whom hearing aids are generally ineffective). Analogously, children who are

127 eligible and receive cochlear implants earlier have better speech perception and spoken

128 language outcomes than those implanted later (Artières, Vieu, Mondain, Uziel, & Venail,

129 2009; Dettman, Pinder, Briggs, Dowell, & Leigh, 2007; Miyamoto, Hay-McCutcheon, Kirk,

Houston, & Bergeson-Dana, 2008; Svirsky, Teoh, & Neuburger, 2004; Yoshinaga-Itano et al.,

2018), with best outcomes for children receiving implants before their first birthday

(Dettman et al., 2007).

Communication. Total Communication refers to communication that combines

speech, gesture, and elements of sign, sometimes simultaneously. Total communication, while

often including elements of sign such as individual signs, is not a full-fledged sign language

like American Sign Language (Mueller, 2013; Scott & Henner, 2020). Clinicians currently

employ total communication as an alternative or augmentative communication method for

children with a wide range of disabilities (Branson & Demchak, 2009; Gibbs & Carswell,

1991; Mirenda, 2003).

Compared to total communication, DHH children using an exclusively oral approach

have better speech intelligibility (Dillon, Burkholder, Cleary, & Pisoni, 2004; Geers et al.,

2017; Geers, Spehar, & Sedey, 2002; Hodges, Dolan Ash, Balkany, Schloffman, & Butts,

1999) and auditory perception (Geers et al., 2017; O'Donoghue, Nikolopoulos, & Archbold,

2000). That said, there is some debate as to whether an oral approach facilitates higher

spoken language performance, or whether children who demonstrate aptitude for spoken

language are steered towards the oral approach rather than total communication (Hall,

Levin, & Anderson, 2017).

1-3-6 Guidelines. Early identification (Apuzzo & Yoshinaga-Itano, 1995; Kennedy

et al., 2006; Robinshaw, 1995; White & White, 1987; Yoshinaga-Itano, Sedey, Coulter, &

Mehl, 1998; Yoshinaga-Itano et al., 2018) and timely enrollment in early intervention

programs (Ching, Dillon, Leigh, & Cupples, 2018; Ching et al., 2013; Holzinger, Fellinger, &

Beitel, 2011; Vohr et al., 2008, 2011; Watkin et al., 2007) are associated with better language

proficiency. Indeed, DHH children who receive prompt diagnosis and early access to services

have been found to meet age-appropriate developmental outcomes, including language (Stika

et al., 2015). In line with these findings, the American Academy of Pediatricians (AAP) has

set an initiative for Early Hearing Detection and Intervention (EHDI). Their EHDI

guidelines recommend that DHH children are screened by 1 month old, diagnosed by 3 months old, and enter early intervention services by 6 months old. We refer to this guideline as 1-3-6. Meeting this standard appears to improve spoken language outcomes for children with HL (Yoshinaga-Itano et al., 2017, 2018) and the benefits appear consistent across a range of demographic characteristics.

At a federal level in the U.S., the Early Hearing Detection and Intervention Act of 2010 (Capps, 2009) was passed to develop state-wide systems for screening, evaluation, diagnosis, and "appropriate education, audiological, medical interventions for children identified with hearing loss," but policies for early diagnosis and intervention vary by state. As of 2011, 36 states (including North Carolina; "15A NCAC 21F .1201 - .1204," 2000) mandate universal newborn hearing screening (UNHS; National Conference of State Legislatures, 2011). All states have some form of early intervention programs that children with hearing loss can access (NAD, n.d.), but the specifics vary state-by-state. For instance, half of the states in the US do not consider mild hearing loss an eligibility criterion for early intervention (Holstrum, Gaffney, Gravel, Oyler, & Ross, 2008); North Carolina does include mild hearing loss in early intervention.

In evaluating the success of this initiative, the AAP (EHDI, n.d.) finds that about 70% of US children who fail their newborn hearing screening test are diagnosed with hearing loss before 3 months old, and that 67% of those diagnosed (46% of those that fail newborn hearing screening) begin early intervention services by 6 months old. These findings suggest that there are breaks in the chain from screening to diagnosis and from diagnosis to intervention, with potential ramifications for the language development of children not meeting these guidelines. We return to this in the discussion.

Quantifying vocabulary growth in DHH children

In what follows, we analyze data from the MacArthur Bates Communicative Development Inventory (CDI, Fenson et al., 1994). This parent-report instrument gathers information about children's vocabulary development, and is commonly used in both research and applied settings. The Words and Gestures version of the form is normed for 8–18-month-olds. On Words and Gestures, parents indicate whether their child understands and/or produces each of the 398 vocabulary items, and answer questions about young children's early communicative milestones. The Words and Sentences version of the form is normed for 16–30-month-olds. On Words and Sentences, parents indicate whether their child produces each of the 680 vocabulary items, and answer some questions about grammatical development. The CDI has been normed on a large set of participants across many languages (Anderson & Reilly, 2002; Frank et al., 2017; Jackson-Maldonado et al., 2003).

The CDI has also been validated for DHH children with cochlear implants (Thal, Desjardin, & Eisenberg, 2007). More specifically, in this validation, researchers asked parents to complete the CDI, administered the Reynell Developmental Language Scales, and collected a spontaneous speech sample. All comparisons between the CDI and the other measures yielded significant correlations ranging from 0.58 to 0.93. Critically, the children in this study were above the normed age range for the CDI, and thus this validation helps to confirm that the CDI is a valid measurement tool for older DHH children. In further work, Castellanos, Pisoni, Kronenberger, and Beer (2016) find that in children with CIs, number of words produced on the CDI predicts language, executive function, and academic skills up to 16 years later. Building on this work, several studies have used the CDI to measure vocabulary development in DHH children (Yoshinaga-Itano et al. (2017); Yoshinaga-Itano et al. (2018); de Diego-Lázaro et al. (2018); Vohr et al. (2008); Vohr et al. (2011); summarized in Table 1). We build on this literature in our analyses below.

Goals and Predictions

This study aims to 1) characterize the demographic, audiological, and intervention variability in the population of DHH children receiving state services for hearing loss; 2) identify predictors of vocabulary delays; and 3) evaluate the success of early identification and intervention efforts at a state level. We include three subgroups of DHH children traditionally excluded from studies of language development: children with additional disabilities, children with unilateral hearing loss, and children from bilingual or non-English-speaking households (e.g., Yoshinaga-Itano et al., 2018; Nicholas & Geers, 2006).

For the first goal, we had reason to expect that many of these variables would be related, due to known causal relations (e.g., cochlear implants recommended for severe hearing loss, but not mild hearing loss). We sought to provide descriptive documentation about the distrubution of demographic, audiological, and intervention characteristics in a diverse sample of DHH children receiving state services. For the second, we hypothesized that male gender, more severe degree of hearing loss, bilateral hearing loss, no amplification use, premature birth, and presence of additional disabilities would predict larger spoken vocabulary delay than female gender, less severe degree of hearing loss, unilateral hearing loss, amplification use, full term birth, and lack of additional disabilities, respectively. We did not have strong predictions regarding the effects of communication method or presence of other health issues (e.g., congenital heart malformation) on vocabulary. For the third goal, based on the prior literatal summarized above, we hypothesized that children with less residual hearing (i.e., bilateral, more severe) and no co-occurring conditions would be earlier diagnosed and earlier to begin language services, and that earlier diagnosis would predict earlier intervention.

Methods

Clinical evaluations were obtained through an ongoing collaboration with the North Carolina Early Language Sensory Support Program (ELSSP), an early intervention program

231 serving children with sensory impairments from birth to 36 months. ELSSP passed along

232 deidentified evaluations to our team after obtaining consent to do so from each family. No

233 eligibility criteria beyond hearing loss and receiving an ELSSP evaluation were imposed,

234 given our goal of characterizing the full range of DHH children with hearing loss in North

235 Carolina.

236   The clinical evaluations included demographic and audiological information, CDI

237 vocabulary scores, and the results of any clinical assessments administered (e.g., PPVT),

238 detailed further below. For some children (n=47), multiple evaluations were available from

239 different timepoints. In these cases, only the first evaluation was considered for this study,

240 due to concerns regarding within-subjects variance for statistical analysis.

241   While this collaboration is ongoing, we opted to pause for this analysis upon receiving

242 data from 100 children. Thus, the reported sample below consists of 100 children (56 male /

243 44 female) ages 4.20–36.20 months (M=21.20, SD=9.10). Race and socioeconomic

244 information were not available. Families were administered either the Words and Gestures or

245 Words and Sentences version of the CDI based on clinician judgement. Children who were

246 too old for Words and Gestures, but who were not producing many words at the time of

247 assessment, were often given Words and Gestures (n=37). Families for whom Spanish was

248 the primary language (n=14) completed the Spanish language version of the CDI

249 (Jackson-Maldonado et al., 2003).

250   With regard to comorbid diagnoses, children in this sample were coded as yes/no for

251 cognitive development concerns (e.g., Down syndrome, global developmental delays; Cornelia

252 de Lange syndrome), yes/no for premature birth (i.e., more than 3 weeks premature), yes/no

253 for health issues (e.g., heart defects, kidney malformations, VACTERL association), and

254 yes/no for vision loss (not corrected to normal by surgery or glasses); see Table 3.

255   Degree of hearing loss was most often reported with a written description (e.g., "mild

sloping to moderate" or "profound high frequency loss"). We created 3 variables: hearing loss in the better ear, hearing loss in the worse ear, and average hearing loss (average of better and worse ear). For the analyses below, we primarily use hearing loss in the worse ear to avoid any redundancies with laterality. Using the ASHA hearing loss guidelines, each of these hearing loss measures was coded with the decibels of hearing loss (dB HL) corresponding with the median dB HL for the level of hearing loss (e.g., moderate hearing loss was coded as 48 dB HL), and sloping hearing loss was coded as the average of the levels (e.g. mild to moderate was coded as 40.5 dB HL). Participants were also coded for unilateral or bilateral hearing loss; presence or absence of Auditory Neuropathy Spectrum Disorder; and etiology of hearing loss (sensorineural, conductive, or mixed). Amplification was recorded as the device the child used at the time of assessment: either hearing aid, cochlear implant, or none. See Table 4 for audiological characteristics of the sample.

Communication method was recorded as spoken language, total communication, or cued speech. One participant had a parent fluent in sign language, but the reported communication method in the home was total communication. No child in our sample used American Sign Language or another signed language. The forms also listed the primary language spoken at home, which we binned into English-speaking and non-English-speaking. 85% of families spoke English, and 14% spoke Spanish. For one child, who was adopted from a non-English-speaking country after their second birthday, we recorded the language background as non-English-speaking, although the child's adoptive parents are English-speaking, because the child had lived most of her life in a non-English-speaking environment. Language and communication information is summarized in Table 5.

Age at screening was measured as the child's age in months at their first hearing screening. Age at screening was available for 68 participants. All participants with a screening age available were screened at birth or while in the NICU. We presume that the vast majority of participants without age at screening received their screening as newborns,

as North Carolina boasts a 98% newborn hearing screening rate (NCDHHS, 2013). Age at

diagnosis was taken as the age in months when children received their first hearing loss

diagnosis. All children were enrolled in birth-to-three early intervention services through

ELSSP, and the date of enrollment was listed on the clinician evaluation. For determining

whether participants met the 1-3-6 guidelines, given the very high rates of early screening

reported in our sample and by the state, we imputed missing data by assuming that children

met the "screening by 1 month" criterion if they met the "diagnoses by 3 months" and

"service enrollment by 6 months" criteria; see Table 6. Finally, we also calculated the number

of hours of early intervention services received per month (including service coordination,

speech therapy, and occupational therapy, among others) based on the clinician report.

Results

We split the results into three parts. In the first, we explore relationships among child

demographic, audiological, and clinical variables. In the second, we use these variables to

predict vocabulary development. Finally, in the third, we describe the implementation of the

EHDI 1-3-6 guidelines and predictors of early diagnosis and intervention in this sample. All

analyses were conducted in R. All code is available on Github.

Part I: Interactions Among Variables

Before we test how these variables may be related to vocabulary, we describe their

relationships to each other. As would be expected, many health, audiological, and clinical

characteristics are not distributed randomly across this sample of children. To quantify this

statistically, we used Bonferroni-corrected chi-square tests between each of our variables

(gender (male/female), laterality (bi-/uni-lateral hearing loss), health issues (yes/no),

developmental delays (yes/no), premature birth (yes/no), language background

(English/non-English), 1-3-6 (yes/no), degree of hearing loss (mild, moderate,

severe/profound as defined above), etiology (sensorineural/conductive), services received per

month (binned into 0-2, 3-6, and >7 - to create maximally evenly sized bins), communication

308 (spoken/total communication) and amplification (hearing aids/cochlear implants/none)).

309 Because the chi-square statistic assumes n > 5 is *expected* in the majority of the cells for

310 each test (preferably $\geq$ 80% McHugh, 2013), we excluded mixed hearing loss (n=8) and cued

311 speech (n=1) from this section of the analysis. Strictly speaking, some variables are not

312 expected to be randomly distributed relative to each other (e.g., premature birth and health

313 issues; degree and amplification), but quantifying the differences via chi-square using a

314 conservative significance threshold lets us highlight the strongest relationships within this

315 dataset.

316   Given that we ran 66 Chi-square tests, Bonferroni-corrected alpha for this set of

317 analyses was p < 0.0007. Of these 66 combinations of variables, p < .05 for 26, and 9

318 survived Bonferroni correction. We are only discussing the latter below, but the full set of

319 results can be found in Figure 1.

320   As expected, we found that health issues, developmental delays, and premature birth

321 were highly interrelated in our sample, such that children born premature were more likely

322 to also experience health issues (X^2 (1, N = 98) = 23.9, p < .0001) and developmental

323 delays (X^2 (1, N = 98) = 11.63, p = .0006), and children with developmental delays were

324 more likely to also experience health issues (X^2 (1, N = 98) = 20.87, p < .0001). Children

325 with developmental delays received more services per month than typically-developing

326 children (X^2 (2, N = 95) = 22.17, p < .0001) and were more likely to use total

327 communication (X^2 (2, N = 98) = 22.51, p < .0001). Likewise, children who used total

328 communication received more services per month than children using spoken language (X^2

329 (4, N = 95) = 21.35, p = .0003).

330   We also confirmed expected relationships among many of the audiological

331 characteristics. There was a significant relationship between laterality and etiology (X^2 (2, N

332 = 88) = 18.29, p = .0001), such that children with conductive hearing loss were more likely

333 to have unilateral hearing loss, and children with sensorineural hearing loss were more likely

334 to have a bilateral loss[2]. Chi-square tests showed that laterality (X^2 (2, N = 98) = 16.43, p

335 = .0003) and degree of hearing loss (X^2 (4, N = 87) = 28.45, p < .0001) were related to

336 amplification in our sample. Children with bilateral hearing loss were more likely than

337 children with unilateral hearing loss to use a hearing aid or cochlear implant; no child with

338 unilateral hearing loss used a cochlear implant, and many children with unilateral hearing

339 loss used no amplification. Regarding degree, children with severe to profound hearing loss

340 were more likely to use a cochlear implant than children with less severe hearing loss (i.e.,

341 mild or moderate).

342 **Part II: Influence on vocabulary**

343   We next turn to the relationship between each of these variables and children's

344 productive vocabulary, as measured by the CDI. Figures 2 & 3 show the vocabulary scores of

345 children in our samples relative to norms for hearing children for English and Spanish

346 respectively. Descriptively, we found widespread vocabulary delays on both Words and

347 Gestures and Words and Sentences, with the majority of DHH children testing around or

348 below the 25th percentile for hearing children (based on WordBank norms; Frank et al.,

349 2017).

350   As noted above, the CDI is composed of two instruments, which differ in number of

351 questions (i.e. the maximum vocabulary score is 398 on Words and Gestures and 680 on

352 Words and Sentences; 428 and 680 respectively for Spanish language CDI). To take this into

353 account, rather than using the raw number of words produced as our outcome variable, we

354 use WordBank norms to establish the difference (in months) between the child's

355 chronological age and their predicted age based on their vocabulary, derived from the

356 WordBank norms (Frank et al., 2017). We call this derived variable *vocabulary delay*.

357   More specifically, to compute a child's predicted age from their vocabulary score, we

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[2] All children with mixed hearing loss (n=8) had bilateral hearing loss.

used the 50th percentile for productive vocabulary from Wordbank data typically-developing

infants [3] (Frank et al., 2017) to create binary logistic growth curves separately for the Words

and Gestures and Words and Sentences versions of the CDI for American English and

Mexican Spanish. For each child, we took the number of words they produced divided by the

number of words on the instrument, to give us the proportion of words produced. We used

this proportion in an inverse prediction from the binary logistic regression curves to generate

a predicted age. That is, for each possible CDI score, the growth curve provided the age that

the score would be achieved for the 50th percentile trajectory. Finally, we subtracted the

predicted age from each child's chronological age to calculate their vocabulary delay.

However, for children producing 0 words, this approach was not appropriate due to the long

tails on the growth curves. Thus, for this subset of children, we took the x-intercept from

Wordbank (8 months for English, and 9 months for Spanish), and subtracted that value from

the child's chronological age to get their vocabulary delay.

To look at the relationship between our predictor variables and CDI scores, we next

conducted multiple linear regression, using vocabulary delay as our outcome variable. [4]

Our full regression model included all variables: Vocabulary Delay ~ Gender +

Developmental Delay + Health Issues + Premature Birth + Laterality + Degree +

Amplification + Communication + Meets 1-3-6 + Services Received Per Month + Language

Background.

This model accounted for significant variance in vocabulary delay (adjusted-$R^2 = 0.59$,

$p < .001$; see Table ??). We next performed stepwise model comparison using stepAIC

(MASS) to pare down the model. This process selects only the predictors which

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[3] Number of hearing children in normative sample for each growth curve: n(WG-English)=1071,

n(WG-Spanish)=760, n(WS-English)=1461, n(WS-Spanish)=1092

[4] We excluded the adopted child from this section of the analysis due to concerns about comparing her score

to the American English CDI norms.

incrementally improved model fit, measured by Akaike's Information Criterion (AIC), which

considers goodness of fit and model complexity (penalizing models with many predictors).

We started model selection with the full model, as described above. We then filtered out

cases where Meets 1-3-6 or Degree was unknown; stepwise AIC selection won't run with

missing values in those columns due to differences in the number of cases. Because Degree

did not improve model fit, the Degree term was removed manually from the model, so that

participants without Degree information were not excluded. Stepwise selection with AIC was

performed again without Degree[5].

Based on this iterative process, we removed several predictors from the model, leaving

the following final model: Vocabulary Delay ~ Age + Laterality + Amplification. This

model accounted for significant variance in children's vocabulary delay to a nearly identical

degree as the full model (adjusted-R^2 = 0.58, p = < .001, see Table 8). We found significant

main effects for Age, Amplification, and Laterality, such that older age, no amplification, and

bilateral hearing loss predicted greater vocabulary delays. Compared to children with no

amplification, children with cochlear implants had a 3.50 months smaller spoken vocabulary

delay (p = .021), and similarly children with hearing aids had a 3.84 months smaller delay (p

= .001). Children with unilateral hearing loss had a 2.70 months smaller delay (p = .020)

than children with bilateral hearing loss. With regard to Age, for each month older, the

model predicted a 15.23 weeks *larger* vocabulary delay (p = .021).

Given our results in Part I revealing relationships exist among several of these variables

(e.g., laterality and amplification), we tested for collinearity concerns by computing the

model's VIF (variance inflation factor). This revealed low levels of collinearity among

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[5] When AIC selection was run excluding the participants without Degree information, the model also

included a non-significant main effect of Developmental Delay. ANOVA revealed that including a

Developmental Delay term did not significantly improve model fit when including the 0 participants without

Degree information.

402 predictors in our final model (all VIF < 1.20; see Table 9; James, Witten, Hastie, &

403 Tibshirani, 2013). In sum, the analyses in this section revealed that over half of the variance

404 in DHH's children's vocabulary scores was explained by their age, whether their receive

405 amplification, and whether their hearing loss was unilateral or bilateral.

406 Part III: Success in Meeting 1-3-6 Guidelines

407 Perhaps of greatest importance to clinicians and policymakers is the implementation

408 and effect of existing policies. Although whether a child met 1-3-6 guidelines was not

409 included in our final model predicting vocabulary delay through our model selection process,

410 its demonstrated importance for language outcomes (e.g., Yoshinaga-Itano et al., 2018)

411 merits further discussion. To this end, we looked at the ages at which children received

412 diagnosis and intervention, and how this mapped onto the 1-3-6 guidelines. In this section,

413 we provide a brief description of the implementation of 1-3-6 in our sample, examine its

414 effect on vocabulary delay, and describe the results of exploratory linear regression models

415 for age at diagnosis and age at intervention.

416 Overall, 37% of our sample met 1-3-6 guidelines for early diagnosis and intervention

417 (see Table 2). Among the children for whom screening information was available (n=68),

418 100% were screened at birth or during NICU stay. 69% of children received diagnosis by 3

419 months of age, and 39% began early intervention by 6 months of age. Among children with

420 comorbidities, 21.05% met 1-3-6 guidelines, compared to 47.37% of children without

421 comorbidities. Figure 5 shows the age at first diagnosis, intervention, amplification, and

422 implantation for each child in our sample.

423 We first tested the link between 1-3-6 and vocabulary directly in an exploratory

424 analysis. An independent samples t-test showed that children who did not meet 1-3-6

425 guidelines had significantly larger vocabulary delays than children who met 1-3-6 guidelines

426 ($t(68.78)=2.62$, $p=0.01$; see Figure 6). The group that did not meet 1-3-6 guidelines was 3.62

months more delayed with regard to vocabulary.

To better understand implementation of 1-3-6 guidelines, we next zoomed in on diagnosis and intervention. We conducted two linear regressions, one for age at diagnosis and one for age at intervention, considering only the predictors that would have been available or relevant at each of these stages (as detailed below). Model selection followed the same stepwise AIC-based process as Part II.

For age at diagnosis, we included the set of child-specific factors that would be relevant *before* diagnosis of hearing loss (e.g., we excluded amplification type because a child would not receive a hearing aid or cochlear implant prior to being diagnosed with hearing loss.) We began with: gender, degree, developmental delay, health issues, prematurity, laterality, language background, and etiology.

The best fit model was: Age at Diagnosis ~ Health Issues + Language Background + Laterality, with significant main effects of Health Issues and Language Background (see Table 10). This model accounted for 16.41% of the variance in age at diagnosis (p = .001). Average age at dianosis was 4.65 months. Relative to English-speaking families, children from Spanish-speaking families were diagnosed 6.47 months later (p = .001). Children with health issues were diagnosed 3.70 months later than children without health issues (p = .01).

We repeated this model selection process for age at intervention. In addition to the variables used to fit the intervention model, we included age at diagnosis. The best fit model was: Age at Intervention ~ Premature Birth + Degree + Age at Diagnosis + Language Background (R^2=0.43 , p < .001; see Table 12, with significant main effects of degree and age at diagnosis. Prematurity (ß = 3.78, p = .06) and language background (ß = -1.38, p = .52) were not significant predictors on their own, but their inclusion improved model fit. Average age at intervention was 11.12 months. More severe hearing loss predicted earlier intervention, such that for every additional 10 dB HL, predicted age at intervention was 4.02

weeks earlier (p < .01). With regard to age at diagnosis, for every month diagnosis was delayed, intervention was delayed by 2.84 weeks (p < .01).

Discussion

In this study, we examined the demographic, audiological, and clinical characteristics of 100 young DHH children in North Carolina. We documented the distribution of these characteristics and explored the relationships between these variables, vocabulary, diagnosis, and intervention. In other, more-controlled samples, the variables studied here have been shown to be relevant for language development, but their effects are less well-understood "in the wild." Here, we found complicated and nuanced relationships among the variables.

Returning to our original three questions, we asked first: how are child-level variables intertwined? We found significant non-random distribution of many of the variables, suggesting that in a real-world sample of children with hearing loss, many factors are not dissociable from each other. This was particularly true for many of the auditory characteristics and comorbid diagnoses; this paper provides the first population-based documentation of this distribution. We next asked whether these characteristics can predict vocabulary outcomes for DHH children. We created a model looking using all of our variables, but found that a model including only children's age, laterality of hearing loss, and amplification type best accounted for the variability in spoken vocabulary outcomes. Finally, we asked: how successful were the 1-3-6 guidelines for early detection and intervention, both in terms of improving child outcomes and ensuring timely diagnosis and intervention for all children with hearing loss? Here, we found that children who met 1-3-6 guidelines indeed had a smaller vocabulary delay. However, only 37% of children met these guidelines. Some of the variability in when children received diagnosis / intervention could be explained by child characteristics.

Some readers might be left wondering what to take away from the complexity of these

results, but the complexity itself is an important piece of understanding outcomes children
with hearing loss. Taken together, these results demonstrate the connectedness of factors
influencing outcomes for the diverse population of Deaf/Hard-of-Hearing children. We next
highlight some possible implications of this study for future research and clinical practice.

How are child-level variables intertwined?

In our sample, we found significant overlap among demographic, audiological, and
clinical variables. Prematurity, health issues, and developmental delay frequently
co-occurred, such that children with one of these conditions were more likely to have any
other condition. This is not surprising. Many conditions that cause developmental delays
have a high incidence of health issues (e.g., heart problems in Down Syndrome; vomiting and
seizures with hydrocephalus), and it is well documented that there is a higher incidence of
developmental delay and health issues in preterm infants (Aarnoudse-Moens,
Weisglas-Kuperus, van Goudoever, & Oosterlaan, 2009; Costeloe et al., 2012; Luu, Katz,
Leeson, Thébaud, & Nuyt, 2016; Pierrat et al., 2017; Robertson et al., 2009; York & DeVoe,
2002). In our sample, we also had a large range of health conditions (76 unique conditions in
our sample of 100 children; see Table 3 and Appendix XXX for more detailed information
about comorbidities). Some studies to date have examined the outcomes of DHH children
with certain conditions (e.g., Clibbens, 2001; Szymanski, Brice, Lam, & Hotto, 2012).
However, because the constellation of comorbid conditions is so varied, an important
direction for future research could be whether cognitive and social abilities, as well as
family's treatment resources, may be predictive of language outcomes across conditions.

We found that children with developmental delays (e.g., Down syndrome) were much
more likely to use a total communication approach than typically-developing DHH children
(i.e., total communication used by `round(perc_DD_TC)`% of DHH children with
developmental delay vs. `round(perc_DD_TC)`% of typically-developing DHH children).
Communication modality was not distributed randomly throughout our sample, with use of

total communication appearing to follow children already at greater risk for verbal delays. Such a pattern is in line with clinical use of manual communication approaches for young children with disabilities (e.g., Branson & Demchak, 2009). This should temper the interpretation of correlational studies finding links between total communication and language delays (e.g., Geers et al., 2017).

We also found relationships among many of our audiological variables. To highlight one such result, amplification devices were more common for children with less hearing (i.e., children with bilateral hearing loss and children with moderate to profound hearing loss). This may be due to the assumption that a hearing aid or cochlear implant will not benefit children with minimal hearing loss (Updike, 1994), although several studies have found benefits for amplification for mild or unilateral hearing loss (Briggs, Davidson, & Lieu, 2011; Hassepass et al., 2013; Priwin, Jönsson, Hultcrantz, & Granström, 2007; Walker et al., 2015; Winiger, Alexander, & Diefendorf, 2016).

The relationships we documented in Part I are not necessarily surprising, given causal links among some of the variables (e.g., increased health issues in children born premature). Nevertheless, it should caution us to think critically about how we construct samples for controlled lab experiments. During study design: how likely is it to collect a desired sample of (e.g.) 32 typically-developing pediatric cochlear implant users with bilateral, severe-to-profound hearing loss, given that such a subsample may only represent roughly 14% of the DHH population, as it does here? During interpretation of the results: how might the findings generalize to the rest of the DHH population given the constraints of the study at hand?

Predicting vocabulary outcomes

We next turn to how these variables may influence vocabulary outcomes. In our sample, 88.89% of DHH children fell below the 50th percentile for spoken

vocabulary\footnote{Of the 11.11% who were at or above the 50th percentile, 55.56% were 8-to-9-month olds who were not yet producing any words (as expected at this age). }. To have such a strong majority of DHH children below the 50th percentile for vocabulary development indicates that this group is not yet well-equipped to acquire spoken language. This disadvantage can have lasting consequences in the lives of DHH children (Karchmer & Mitchell, 2003; Kyle & Harris, 2010; Qi & Mitchell, 2012).

In contrast to our predictions, the best model predicting vocabulary delay had just a few variables: age, amplification, and laterality. Notably, we did not simply find that DHH children were learning words at the same rate (albeit delayed) as hearing children, which would have led to a constant delay across developmental time. Instead, we see that the spoken vocabulary delay widens with age, indicating that the rate of spoken vocabulary acquisition is slower for DHH children. The result is a population increasingly behind on spoken language milestones, and given that none of the children here use sign language, on language development more broadly.

Few studies directly assess language development differences between unilateral and bilateral hearing loss. Our model results suggest that children with bilateral hearing loss are at a quantifiable disadvantage over children with unilateral hearing loss. However, children with unilateral hearing loss still experience notable delays both in the literature (Kiese-Himmel, 2002; Lieu, 2004, 2013; Lieu et al., 2012; Vila & Lieu, 2015) and in our sample (Mean delay_{unilateral} = 7.18). Similarly, in our sample, children without amplification were 3-4 months more delayed than children with hearing aids or cochlear implants. This increased delay for children without amplification or with bilateral hearing loss could reflect decreased spoken language audibility (Anne et al., 2017; Lieu, 2013; Tomblin et al., 2015; Vohr et al., 2008).

Predicting early diagnosis and intervention

Lastly, we explored the implementation of 1-3-6 guidelines. Only 36.84% of children met the EHDI guidelines for diagnosis by 3 months and intervention by 6 months, despite ample evidence suggesting early diagnosis and intervention improve language outcomes (Apuzzo & Yoshinaga-Itano, 1995; Ching et al., 2013; Holzinger et al., 2011; Kennedy et al., 2006; Robinshaw, 1995; Vohr et al., 2008, 2011; Watkin et al., 2007; White & White, 1987; Yoshinaga-Itano et al., 1998, 2018). Children in our sample who met 1-3-6 guidelines were 3.62 months *less* delayed in spoken vocabulary than children who were late to receive diagnosis and/or services. With these demonstrable benefits in mind, our sample, by dint of accepting all children receiving early intervention services in one state, was able to explore naturally occurring variance in *who* received on-time diagnosis and intervention.

Diagnosis.   In the case of diagnosis, having health issues or a non-English language background predicted later diagnosis. Children with health issues were diagnosed 3.70 months later than infants without health issues. One possible explanation is that the health issues caused acquired hearing loss that wouldn't be detected by the newborn hearing screening, thus delaying identification of hearing loss. In our sample, 16 of the 36 children with health issues had conditions that might cause acquired hearing loss (i.e., meningitis, sepsis, jaundice, seizures, hydrocephalus, MRSA, anemia, frequent fevers, cytomegalovirus). While acquired hearing loss may be one driver of delayed diagnosis for children with health issues, this accounts for only a fraction of the subpopulation with health issues. Another possible explanation is that the health issues required more pressing medical attention than the possible hearing loss. Families and medical providers had to prioritize treatment for the health issue (e.g., surgery for congenital heart defect) over diagnostic audiology services.

Infants from Spanish-speaking families were diagnosed 3.78 months later than infants from English-speaking families. This may be due to cultural differences in attitudes towards deafness (Caballero, Muñoz, Schultz, Graham, & Meibos, 2018; Rodriguez & Allen, 2020;

578 Steinberg, Bain, Li, Delgado, & Ruperto, 2003; Steinberg, Dávila, Collazo, Loew, &

579 Fischgrund, 1997) or it may result from a lack of linguistically accessible and culturally

580 appropriate audiology services. Only 5.6% of American audiologists identify as a bilingual

581 service provider (ASHA, 2019), and services from a monolingual provider may be insufficient.

582 To this point, Caballero et al. (2017) found that Hispanic-American parents of DHH children

583 wish for more concrete resources, comprehensive information, and emotional support from

584 their audiologist. In a nationwide survey of audiologists, the majority of audiologists

585 reported that language barriers presented a major challenge in working with

586 Spanish-speaking families, specifically in obtaining the child's case history and providing

587 recommendations for follow-up services (Abreu, Adriatico, & DePierro, 2011).

588   **Intervention.**   As expected, more severe hearing loss predicted earlier intervention,

589 such that for every additional 10 dB HL, predicted age at intervention was 4.02 weeks earlier.

590 This converges with findings by Harrison, Roush, and Wallace (2003) in which

591 severe-to-profound hearing loss was diagnosed 2-5 months earlier than mild-to-moderate

592 hearing loss. Parents and clinicians may adopt a wait-and-see approach to intervention for

593 children with some residual hearing. Nevertheless, mild-to-moderate hearing loss is

594 associated with language delays and academic challenges (Blair et al., 1985; Delage & Tuller,

595 2007), which early intervention may offset.

596   Age at start of services was also associated with age at diagnosis: for every month

597 diagnosis was delayed, intervention was delayed by 2.84 weeks. Ching et al. (2013) found

598 that age at intervention predicted better outcomes for DHH children, above and beyond age

599 at diagnosis. Of course, these two variables are related, such that we cannot hope to achieve

600 early intervention goals without ensuring children receive timely diagnosis. Early diagnosis

601 puts children in the pipeline towards intervention earlier.

602   A final point regarding 1-3-6 attainment: this sample is composed of children receiving

603 birth-to-3 services. An estimated 67% of children with hearing loss enroll in early

intervention services (CDC, 2018). While this represents a tremendous step forward in prompt early intervention services relative to just a few decades prior, early intervention may not be early enough. Less than 39% of our sample of children in early intervention meet the 6-month EHDI benchmark. Furthermore, an unknown fraction of the DHH population in North Carolina aren't included in this analysis because they have not been enrolled in services by 36 months. The AAP estimates that almost 36% of infants who do not pass a newborn hearing screening are lost to follow-up. Assuming that the population of children in early intervention only represents two thirds of the population with hearing loss, our data suggest that the actual proportion of DHH children who receive intervention by the EHDI-recommended 6 months may be closer to 26%. These children may not receive clinical support until school-age or later.

Educational and Clinical Implications

Despite high rates of newborn hearing screening in North Carolina, and even relatively high rates of diagnosis by 3 months (66/100 children in our sample), most children in our sample did not meet the 1-3-6 guidelines. Based on our analyses, we have the following recommendations for increasing attainment of 1-3-6 guidelines:

1. Frequent hearing screenings for children receiving medical or therapeutic care for health issues.

2. Service coordination for families balancing multiple co-occurring conditions.

3. Expansion of bilingual clinicians both in-person and teletherapy clinicians to provide therapy and service coordination to non-English-speaking families.

4. Provision and encouragement of early intervention services for children with mild to moderate hearing loss.

Additionally, the vast majority of children in our sample experienced vocabulary delays

(relative to hearing peers), and studies of spoken vocabulary development in older DHH children suggest that they may not catch up (Lund, 2016). This should set clinicians and educators on high alert, due to the demonstrated importance of vocabulary skills in literacy (Biemiller, 2003; Hemphill & Tivnan, 2008; Stæhr, 2008) and in education more broadly (e.g., Young, 2005; Monroe & Orme, 2002). As early intervention predicts vocabulary outcomes in study after study (including this present study and e.g., Vohr et al., 2008, 2011; Ching et al., 2018, 2013; Holzinger et al., 2011; Watkin et al., 2007), ensuring intervention by 6 months for all DHH children may be one way to address spoken vocabulary deficits. Another solution: even prior to intervention or amplification, provision of structured, accessible language input (i.e., sign language) may mitigate negative effects of auditory deprivation on language skills (Davidson, Lillo-Martin, & Pichler, 2014; Hassanzadeh, 2012; Spellun & Kushalnagar, 2018). Indeed, while we recognize that learning sign language may pose a challenge for some families for myriad reasons, and as noted above, our sample did not use sign language, we nevertheless feel it is worth underscoring as an important language support for DHH children and their families.

In recommending sign language, we follow the rationale set forth by Hall, Hall, and Caselli (2019), summarized here: Spoken language outcomes for DHH children are variable and unpredictable (Ganek, McConkey Robbins, & Niparko, 2012; Szagun & Schramm, 2016), and even in optimal situations, many DHH children do not achieve age-appropriate spoken language outcomes (e.g., Geers et al., 2017). Failing to achieve language proficiency (in any language) confers higher risk of disrupted cognitive, academic, and socioemotional development (Amraei, Amirsalari, & Ajalloueyan, 2017; Dammeyer, 2010; Desselle, 1994; Hall et al., 2017; Hrastinski & Wilbur, 2016; Kushalnagar et al., 2011; Moeller & Schick, n.d.; Preisler, Tvingstedt, & Ahlström, 2002; Schick, De Villiers, De Villiers, & Hoffmeister, 2007). The available data do not suggest that sign language harms spoken language development (Davidson et al., 2014; Park et al., 2013), and in fact, some studies suggest that sign language *benefits* spoken language development (e.g., Hassanzadeh, 2012). Providing

early access to a natural sign language offers children another path to language mastery, and use of sign language does not preclude learning spoken language. Thus, we encourage sign language use *at least* prior to mastery of spoken language, and when possible for the family, we encourage its continued use as a language resource.

Limitations and Opportunities for Future Work

This study represents an important first step in quantifying variability in demographic characteristics, language outcomes, and 1-3-6 attainment. However, due to the exploratory nature of the study, its limited geographic scope, and the variability of the sample, it may be unclear what readers should take away from these results. These potential limitations represent opportunities for future investigators to better understand the complex factors influencing DHH children's outcomes.

These analyses were exploratory, and there were many possible analytic routes. That said, our results largely converge with or replicate key aspects of past studies (e.g., Ching et al., 2013) and received wisdom among clinicians. In the interest of transparency, these data and all code generating our results are available on our OSF page (XXX) and we encourage those interested to explore further analyses.

This sample is composed only of children in North Carolina, and certain factors vary by country and by state (e.g., diagnosis and early intervention practices; NAD, n.d.). However, based on other demographic research (Blackorby & Knokey, 2006; Institute, 2014), our sample largely resembles the national DHH population in terms of degree of hearing loss, percentage of children with additional disabilities, cochlear implant and hearing aid use, language background, and gender. We would exercise caution in applying these results to regions where sign language access for DHH children is more common (e.g. Washington D.C.; Rochester, New York.) A similar naturalistic study in those regions could help illuminate the effects of different clinical and demographic factors in a signing population

680   Furthermore, the considerable variability in the sample did not allow us to easily

681 isolate effects of different characteristics. However, this variability is real-world variability,

682 and as we demonstrated earlier, many of these variables co-occurred such that it may not

683 make sense to isolate. Larger sample sizes, which are often difficult to achieve in research

684 with DHH children, would help to tease apart different effects. As researchers continue to

685 study influences on vocabulary in DHH children, a meta-analytic approach may be able to

686 better estimate effects and effect sizes within the varied outcomes of this diverse population.

<p align="center">687   Conclusion</p>

688   Using a diverse sample of 100 children enrolled in early intervention, we provide a

689 description of children's demographic and audiological characteristics, vocabulary outcomes,

690 and clinical milestones. Our results suggest that the children's characteristics of young DHH

691 children have implications for other characteristics, vocabulary outcomes, and timing of

692 clinical intervention.

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Table 1

Summary of findings of CDI studies in DHH children.

Study	Population	Gender	1-3-6	Laterality	Degree	Amplification	Communication	Comorbidities
Yoshinaga-Itano et al., 2017	8-39 month children with bilateral hearing loss	No effect	1-3-6 +	Did not study	More severe -	Did not study	Did not study	Comorbidities -
Yoshinaga-Itano et al., 2018	Children with cochlear implants	Did not study	1-3-6 +	Did not study	Did not study	Earlier CI activation +	Did not study	Did not study
De Diego-Lazaro et al., 2018	Spanish speaking children with bilateral hearing loss	No effect	Earlier intervention +	Did not study	Milder +	More functional hearing +	Did not study	Did not study
Vohr et al., 2011	18-24 month olds with hearing loss	Did not study	Earlier intervention +	Did not study	Milder +	Did not study	Did not study	NICU stay -; Comorbidities -

^a + equals bigger vocab, - equals smaller vocab

Table 2

CDI details: For each version, average age, comprehension score, production score of participants in our sample (with standard deviations in parentheses). Final column shows the percentage of children administered the version who were diagnosed with developmental delays.

CDI version	Average Age (SD)	Average Comprehension (SD)	Average Production (SD)	% Developmental Delays
WG (n=74)	20.05 (8.82) months	105 (99.7) words	32 (53.4) words	18.9%
WS (n=24)	26.03 (7.78) months	NA	149 (180.1) words	4.2%

Table 3

Additional Diagnoses (n=39): Ns of participants in our sample diagnosed with other conditions. N.B.: Ns do not sum to total because many participants had multiple diagnoses.

Condition	Specific Condition	n
Premature		17
	Extremely Premature	11
	NICU stay	16
Health Issues		36
	Heart	9
	Lung	5
	Illness	15
	Feeding Issues	14
	Pregnancy/Birth Complications	11
	Musculoskeletal	9
	Cleft Lip/Palate	4
	Other	15
Developmental Concerns		17
	Down Syndrome	5
	Chromosomal Issues	2
	Neural Tube Defects	2
	Other	10
Vision Loss		5
	Retinopathy of Prematurity	1
	Nearsightedness	1
	Farsightedness	1
	Cortical Visual Impairment	1

Table 4

Audiological Characteristics of the Sample: First two columns describe laterality and amplification type (cochlear implant, hearing aid, or none). Next two columns show mean decibels of hearing loss in better/worse ear for the subset of the population given that combination of laterality and amplification. Last two columns describe age (in months) at amplification or cochlear implantation (if applicable) for the laterality-amplification subset.

Laterality	Amplification	mean_HLbetter	mean_HLworse	mean_age_amplification	mean_age_implantation
Bilateral	CI	85.60	89.79	11.29	14.12
Bilateral	HA	47.02	55.57	8.28	NaN
Bilateral	none	49.67	53.65	NaN	NaN
Unilateral	HA	4.70	56.04	10.91	NaN
Unilateral	none	2.50	73.90	8.50	NaN

Table 5

Language and Communication Characteristics of the Sample: Ns of participants by language background and communication method.

Communication	English	Hindi	Spanish	Total
cued speech	1	0	0	1
spoken	68	1	10	79
total communication	15	0	3	18

Table 6

Meets 1-3-6 Information: Percent of the sample meeting diagnosis and/or intervention guidelines, and average age diagnosis/intervention was provided.

Diagnosis by 3 months	69.47%
Average Age Diagnosis (SD)	4.65 (7.19) months
Intervention by 6 months	39.18%
Average Age Intervention (SD)	11.12 (8.54) months
Meets 1-3-6	36.84%

Table 7

Detailed information about the variables studied. For categorical variables, levels are described. For continuous variables, range, mean, and standard deviation are provided.

Variable	Scale	Range
Age	Continuous	4.2-36 months (mean (SD): 21 (9.1))
Age at Amplification	Continuous	2-30 months (mean (SD): 9 (6.7))
Age at Diagnosis	Continuous	0-30 months (mean (SD): 5 (7.2))
Age at Implantation	Continuous	7-32 months (mean (SD): 14 (7.2))
Age at Intervention	Continuous	1-33 months (mean (SD): 11 (8.5))
Amplification	Categorical	Hearing Aid / Cochlear Implant / None
Communication	Categorical	Spoken / Total Communication / Cued Speech
Degree Hearing Loss (worse ear)	Continuous	17.75-100 dB HL (mean (SD): 64 (24))
Developmental Delay	Categorical	Yes / No
Gender	Categorical	Female / Male
Health Issues	Categorical	Yes / No
Language in Home	Categorical	English / Other
Laterality	Categorical	Unilateral / Bilateral
1-3-6	Categorical	Yes / No
Premature Birth	Categorical	Full-term / Premature
Services Per Month	Continuous	0-43 services per month (mean (SD): 6 (6.4))
Etiology	Categorical	Sensorineural / Conductive / Mixed
CDI - Words Produced	Continuous	0-635 words (mean (SD): 61 (111.2))

Table 8

Unstandardized beta weights (months of vocabulary delay) for the model of vocabulary delay selected by AIC: Vocabulary Delay ~ Age + Laterality + Amplification.

term	estimate	std.error	statistic	p.value
(Intercept)	-0.5358566	1.7146748	-0.3125121	0.7554545
LateralityUnilateral	-2.6985772	1.1372498	-2.3728974	0.0200189
AmplificationCI	-3.5034202	1.4859023	-2.3577730	0.0207969
AmplificationHA	-3.8355930	1.1347744	-3.3800490	0.0011172
Age	0.5493529	0.0558699	9.8327171	0.0000000

Table 9

Generalized Variance Inflation Factor (GVIF) for the model of vocabulary delay selected by AIC: Vocabulary Delay ~ Age + Laterality + Amplification.

	GVIF	Df
Laterality	1.178895	1
Amplification	1.200583	2
Age	1.019896	1

Table 10

Unstandardized beta coefficients (months) for the model of age at diagnosis selected by AIC: Vocabulary Delay ~ Health Issues + Language Background + Laterality.

term	estimate	std.error	statistic	p.value
(Intercept)	9.384015	1.967599	4.769272	0.0000069
HealthIssuesyes	3.703441	1.418520	2.610778	0.0105472
Monolingual_Englishyes	-6.469065	1.957318	-3.305066	0.0013545
LateralityUnilateral	-2.148902	1.575573	-1.363886	0.1759312

Table 11

Variance Inflation Factor for diagnosis model: Vocabulary Delay   Health Issues + Language Background + Laterality.

	VIF	Df
HealthIssues	1.002092	1
Monolingual_English	1.025896	1
Laterality	1.027814	1

Table 12

Unstandardized beta coefficients (months) for the model of age at intervention selected by AIC: Vocabulary Delay   Degree + Prematurity + Language Background + Age at Diagnosis.

term	estimate	std.error	statistic	p.value
(Intercept)	14.6545372	2.8717392	5.1030181	0.0000022
HLworse	-0.0925203	0.0302741	-3.0560849	0.0030365
IsPrematureyes	3.7839323	1.9540853	1.9364212	0.0563036
IdentificationOfHLMonths	0.6520471	0.1044276	6.2440093	0.0000000
Monolingual_Englishyes	-1.3846263	2.1177275	-0.6538265	0.5150755

Table 13

Variance Inflation Factor for the intervention model: Vocabulary Delay   Degree + Prematurity + Language Background + Age at Diagnosis.

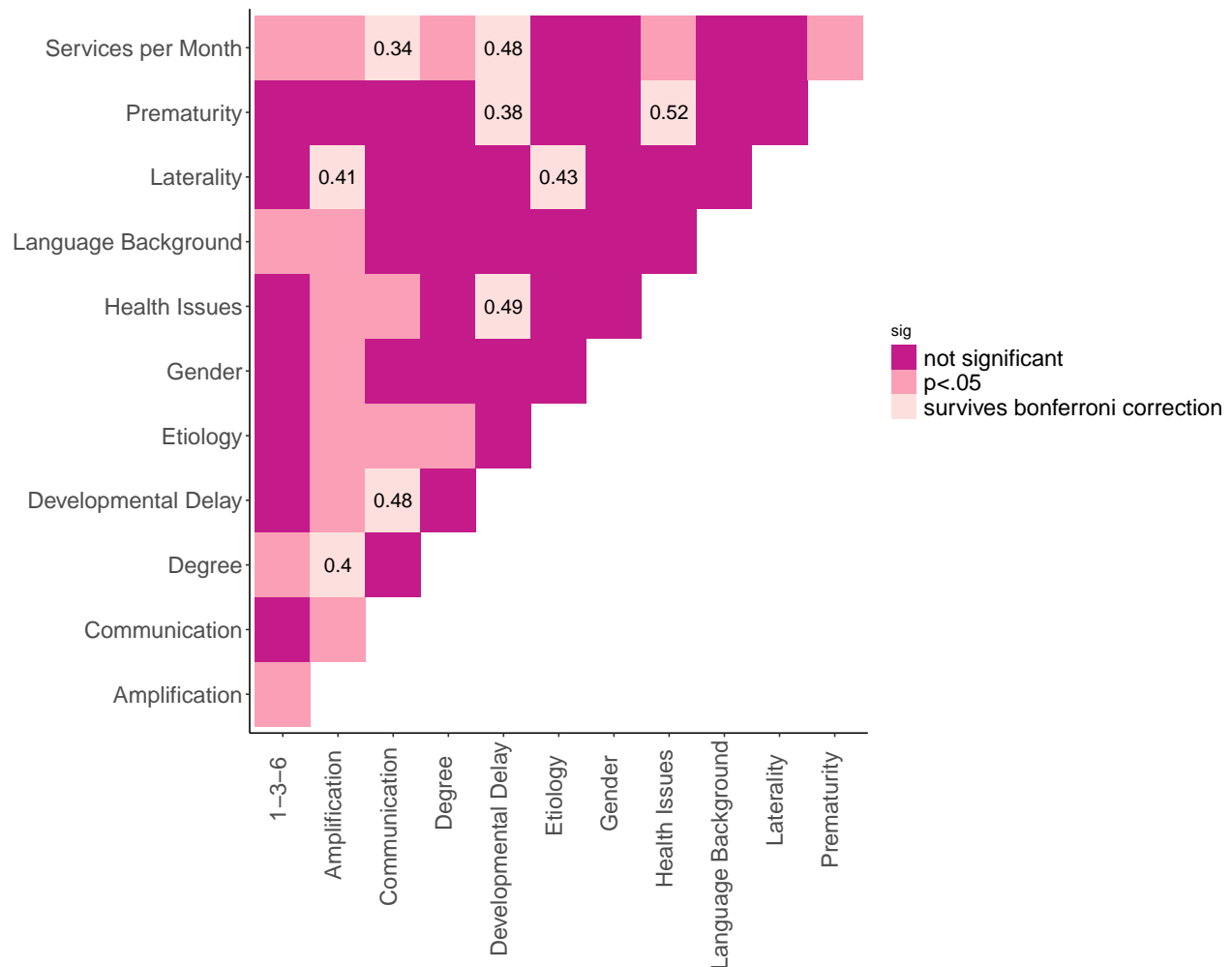|	VIF	Df
HLworse	1.030540	1
IsPremature	1.064463	1
IdentificationOfHLMonths	1.068221	1
Monolingual_English	1.101377	1

Figure 1. Results of chi-square tests between variables. X- and y-axes show the variables compared. Color of the square represents significance of the corresponding chi-square test. For tests that survived Bonferroni correction (p<.0007), effect size (Cramer's V) is given.
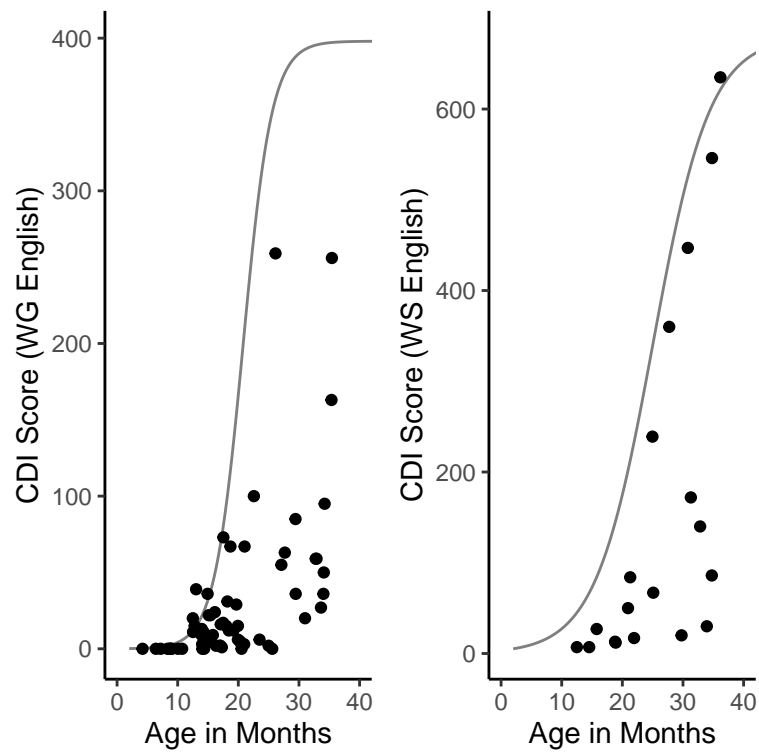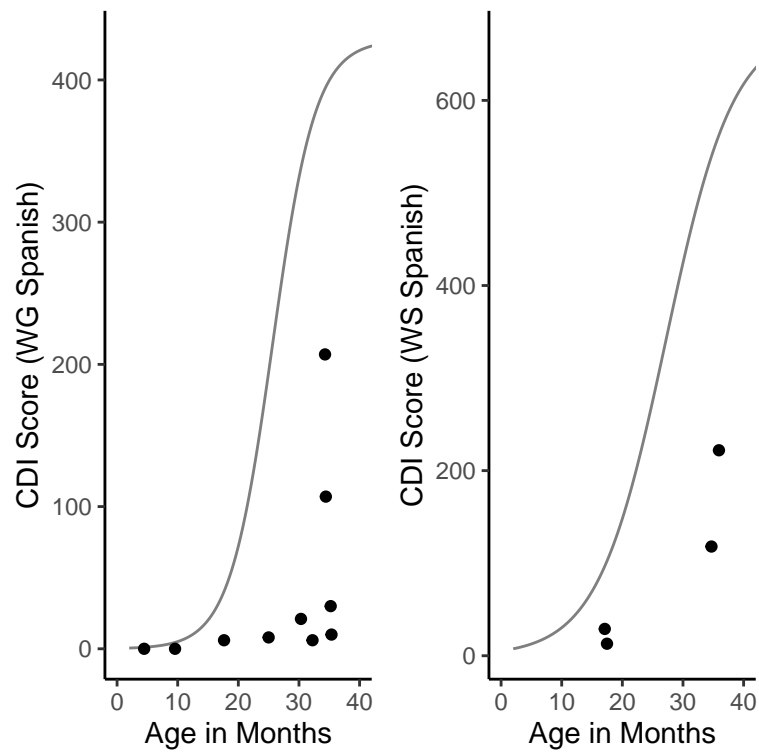
Figure 2. Lines show the growth curves created from Wordbank American English 50th percentile data. Left panel shows Words & Gestures; right panel shows Words & Sentences. Dots represent vocabulary scores of individual DHH children in the sample.

Figure 3. Lines show the growth curves created from Wordbank Mexican Spanish 50th percentile data. Left panel shows Words & Gestures; right panel shows Words & Sentences. Dots represent vocabulary scores of individual DHH children in the sample.
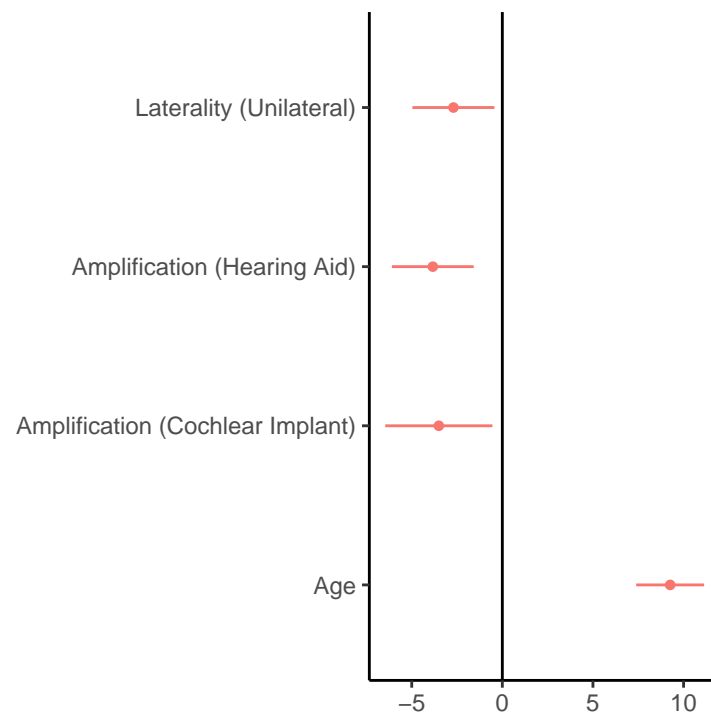
Figure 4. Unstandardized beta weights (months of vocabulary delay) for the model of vocabulary delay selected by AIC: Vocabulary Delay ~ Age + Laterality + Amplification.
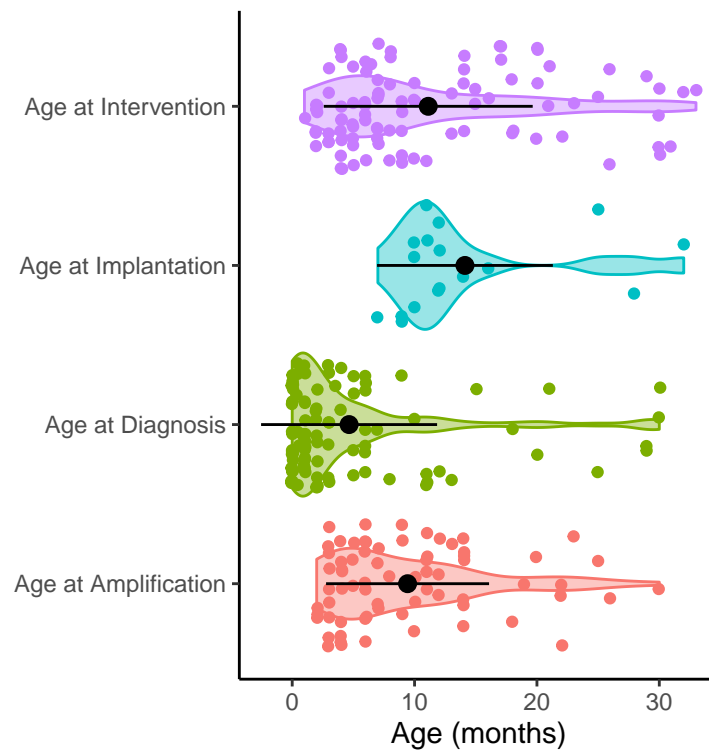
Figure 5. Violin plots for age at diagnosis, intervention, amplification, and cochlear implantation. Each dot represents the age that one child received the clinical service. Blacks dot and whiskers show means and standard deviations.
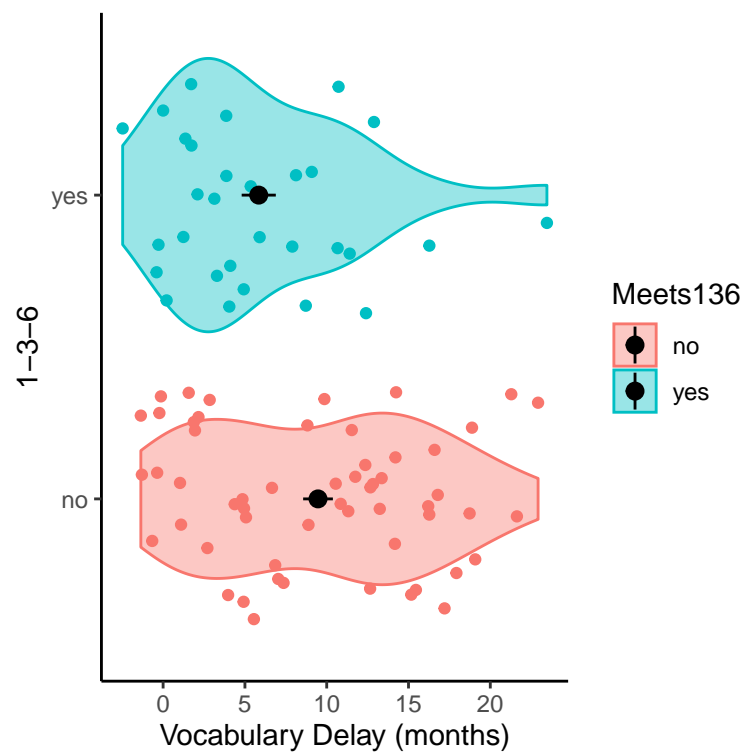
Figure 6. Violin plots showing vocabulary delay for children who meet 1-3-6 guidelines for diagnosis/intervention (top violin) and children who do not (bottom violin). Each dot represents one child in the sample. Blacks dot and whiskers show means and standard error.
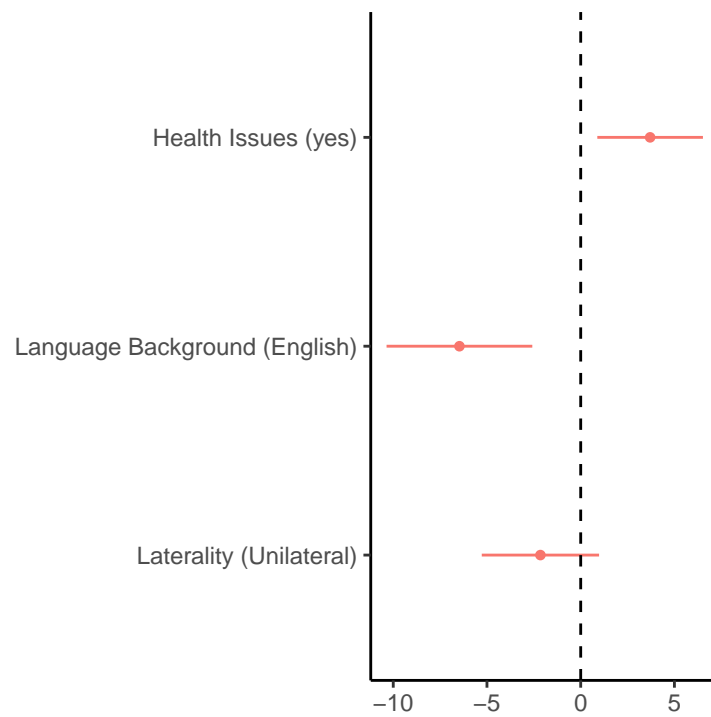
Figure 7. Unstandardized beta weights (months) for the model of age at diagnosis selected by AIC: Vocabulary Delay ~ Health Issues + Language Background + Laterality.
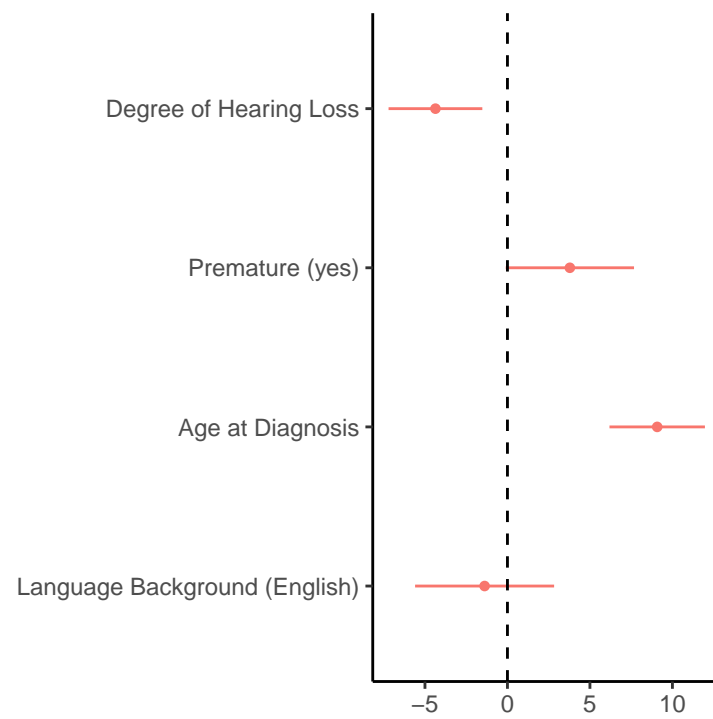
Figure 8. Unstandardized beta coefficients (months) for the model of age at intervention selected by AIC: Vocabulary Delay ~ Degree + Prematurity + Language Background + Age at Diagnosis.