Washington University in St. Louis

Washington University Open Scholarship

Arts & Sciences Electronic Theses and Dissertations

Arts & Sciences

Expressive Vocabulary Development in Very Young Children who are Deaf or Hard of Hearing

Amanda Mcnamara Rudge
Washington University in St. Louis

Recommended Citation

WASHINGTON UNIVERSITY IN ST. LOUIS

Program in Speech and Hearing Sciences

Dissertation Examination Committee:
William Clark, Chair
Joe Barcroft
Heather Grantham
Amanda Ortmann
Mitchell Sommers
Nancy Tye-Murray

Expressive Vocabulary Development in Very Young Children who are Deaf or Hard of Hearing
by
Amanda Rudge

A dissertation presented to
The Graduate School
of Washington University in
partial fulfillment of the
requirements for the degree
of Doctor of Philosophy

May 2020
St. Louis, Missouri

Table of Contents

List of Figures

List of Tables

<u>Acknowledgments</u>

It is with deep gratitude that I acknowledge Heather Grantham, who spent a considerable amount of time supporting my development as a teacher and researcher. Her knowledge, competence, and care served as a guiding light throughout my doctoral journey. I thank William Clark for sharing his expertise and encouraging my professional growth. I also express gratitude to Mandy Ortmann, who was an invaluable guide in this process, as well as a source of inspiration. The members of my committee, Joe Barcroft, Mitch Sommers, and Nancy Tye-Murray, were generous in their time, feedback, and guidance, and for that I am thankful. It has been an honor to work with each of you.

I would also like to thank the administration, teachers, and staff at the Moog Center for Deaf Education. It was under the guidance of my unofficial mentors at the Moog Center, Jean Moog and Betsy Brooks, that I was able to engage in the world of research in deaf education. Without their support, this work would not have been possible.

It is with a full heart that I thank my family. To my husband, Brad, an immense thank you for serving as the foundation of my support system and inspiring me daily. He has celebrated each of my accomplishments as if they were his own and empowered my every step in this arduous process. A very special thank you also to my parents, who have been constant sources of inspiration to me all my life. My parents' early examples of perseverance and passion instilled in me the ambition and drive to contribute to our world and achieve my dreams. I am so fortunate to have you all in my life.

Amanda Rudge

Washington University in St. Louis

May 2020

ABSTRACT OF THE DISSERTATION

Expressive Vocabulary Development in Very Young Children who are Deaf or Hard of Hearing

by

Amanda McNamara Rudge

Doctor of Philosophy in Speech and Hearing Sciences

Washington University in St. Louis, 2020

Professor William Clark, Chair

This longitudinal study aimed to explore the expressive vocabulary growth rate of children ages birth to three years, who are deaf or hard of hearing (d/hh). An additional aim was to investigate hours of direct instruction received during early intervention as a factor that may contribute to the trajectories of expressive vocabulary growth in young children who are d/hh. Hierarchical linear modeling with growth curve analysis was used to investigate expressive vocabulary growth in a population of d/hh children using multiple points of longitudinal vocabulary data. A total of 417 assessments across the 105 participants were analyzed to determine the average rate of growth and to construct expected growth trajectories based on the amount of intervention services received prior to age three. Results indicated positive linear growth trajectories with an average growth rate of 4.75 new words expressed per week (approximately 19 words per month) for a child identified as d/hh by six months of age with no additional diagnoses and who received four hours of intervention per week. This growth rate was less than what can be expected for typically-hearing children. Additional hours of intervention positively contributed to expressive vocabulary rates for children under three years of age. This study recommends increased hours of intervention prior to age three which exceed current intervention guidelines.

Chapter 1: Introduction

When a child utters his or her first word, parents and caregivers rejoice. The child has achieved a milestone that he or she has been investing brain power and motor skills into accomplishing for around a year's time. Over the course of the child's life up until this production of a word, she employed her instinctual word learning abilities. She listened to her world for important sounds, decided that speech sounds were amongst the most meaningful, observed her caregivers' vocal patterns and articulator movements, practiced mirroring what she saw and heard, and finally – finally – she produced a word with meaning and intent. As innate as this process may have been, her caregivers are right to rejoice. The first word is a major achievement in expressive vocabulary development; a foundational step toward linguistic and communicative competence.

For a young child who is born deaf or hard of hearing (d/hh), the process described above is not as innate. In the United States, 1.4 in 1000 children are born with congenital hearing loss (Center for Disease Control and Prevention [CDC], 2019a), and 96% of these children are born to typically-hearing (TH) parents who use spoken language (Mitchell & Karchmer, 2004). This means that for 96% of children who are born d/hh, the path to language development is one that they are not necessarily pre-equipped for without intervention from their caregivers. Caregivers have a choice to make with regard to helping their child gain full access to the path to linguistic competence. Caregivers may choose to: a) learn a new language themselves, a signed visual or tactile language, in order to then give their children access to this language, or b) explore options for amplification to give their child access to the family's home language. For the duration of

this dissertation study, the term *children who are d/hh* will refer to the children who are d/hh and learning spoken language.

A child who is born d/hh does not experience listening time in utero, nor in the early days, months, or even years before identification of hearing loss and subsequent fitting with appropriate amplification via assistive listening technology. Once amplified, the child must then learn how to listen. The innate process of vocabulary development described above for a child who is TH does not become innate as soon as amplification is fit for the child who is d/hh. Instead, the child must be explicitly taught to both attend to and to distinguish between important sounds like phonemes and morphemes. Additionally, children need clear instruction to discern meaning from these small units of sound, determine word break patterns, connect sound to meaning, receptively build a basis of knowledge for learning new words, and eventually produce speech sounds and words. Each step of the way the child who is d/hh benefits from explicit instruction and intervention for success.

Vocabulary is essential for any child's success, regardless of hearing status. A robust lexical knowledge contributes to one's development of thought processing, listening comprehension, reading comprehension, spoken language, written language, and abilities to learn through language. Even when measured at young ages, vocabulary size has been shown to be a strong predictor of later linguistic and academic outcomes (Duff, Reen, Plunket & Nation, 2015; Suggate, Schaughency, McAnally & Reese, 2018; Walker, Greenwood, Hart, & Carta, 1994). Vocabulary words serve as the building blocks to higher level complex language, and just as TH peers learn single words before word combinations and simple to complex sentences, children who are d/hh need to do the same.

This introductory chapter will provide general information about very early auditory development and vocabulary learning in a TH population, followed by a discussion of the early development of auditory skills and vocabulary in children who are d/hh. Both receptive vocabulary, or words the child understands, and expressive vocabulary, or words the child produces, will be discussed. Unless otherwise indicated, the term *vocabulary* will be used to collectively refer to both receptive and expressive lexicons. This chapter will also review factors that may contribute to expressive vocabulary growth in very young children who are d/hh.

1.1   Development of Children who are TH

For families who have chosen to use cochlear implants and/or hearing aids with their child, the desired outcome is often listening and spoken language that is consistent with their TH peers. For this reason, the general population of typically-developing children, with normal hearing, serve as a models and benchmarks for the population of children with hearing loss who are learning to listen and talk. The following sections will review the development of auditory systems and spoken language lexicons in the absence of hearing loss.

1.1.1 Early Auditory Development in TH Children

For children who are typically developing and have normal hearing levels, the foundations of spoken vocabulary development begin prior to birth, with early auditory access. The human auditory system develops in utero, beginning at about 16 weeks, with especially critical periods of neurosensory development between about 25 weeks' gestation and about 5 to 6 months post-birth (Graven & Browne, 2008). This means that auditory information is accessible, and perhaps interpretable, to fetuses while still in the womb. A study by Moon, Lagercrantz, and Kuhl in 2013 investigated infants' abilities to distinguish between native and foreign language

phonemes just hours after birth, hypothesizing that language experience in utero would affect speech perception after birth. In this study, forty Swedish-born and forty English-born infants, who were all TH and otherwise developmentally average, were able to distinguish between native and non-native vowels at time of test, which was on average just 33 hours after birth. For weeks prior to birth, the eighty neonates in the study had access to information through their typically-developing auditory systems, such as caregivers' voices and possibly environmental sounds, priming the infants' auditory systems and brains for their native language sounds to be identified almost immediately after birth. This exceptionally early example of native language discrimination indicates an innate human capability of speech perception.

Similar speech perception mechanisms have been observed and documented in the weeks, months, and years following birth, as well. A seminal study by Eimas, Siqueland, Jusczyk, and Vigorito in 1971 showed the remarkable abilities of 1- and 4-month-old infants to distinguish between phonemes [b] and [p], which differ in voiced onset timing (VOT) by only milliseconds. The researchers used high amplitude sucking procedures to measures infants' discrimination abilities between two speech stimuli, phonemically represented here in International Phonetic Alphabet symbols: [bɑ] and [pɑ] (Brown, 2012). Both age groups of participants, one month and four-month-olds, were able to detect the difference between the stimuli, evidencing an early and innate human ability to categorically perceive minute differences in speech. Many subsequent experiments confirmed Eimas and colleagues' findings, as well as added evidence that infants are not only able to detect phonetic changes in vowels, but they can also perceive differences in voicing, manner, and place of articulation in syllabic consonants (e.g. Bertoncini, 1993; Eilers, Bull, Oller, & Lewis, 1984; Eimas, 1974).

4

In addition to the ability to differentiate between minuscule phonemic differences across languages in VOT down to the millisecond (Eimas et al., 1971), infants who are TH also possess the ability to specialize in their native language in the first several months of life, an ability which in turn influences native language vocabulary outcomes in the second year of life (Tsao, Liu, & Kuhl, 2004). Tsao and colleagues conducted a longitudinal study with 28 typically-developing six-month-olds to examine the role of early phonetic perception in language acquisition, including vocabulary development. The speech perception skills of these infants at 6 months affected their lexical development at 13, 16, and 24 months of age, with the most significant impact at two years of age, during a robust period of language development in a child's life. These powerful speech perception skills (Eimas et al., 1971; Moon et al., 2013; Tsao et al., 2004) are the important foundations which infants need to recognize phonological information in connected speech streams, parse apart word boundaries, and build lexical knowledge.

For children who are TH, learning vocabulary stems from the above discussed powerful perception mechanisms that can be observed as early as hours after birth into childhood. A ground-breaking study done by Saffran, Aslin, and Newport in 1996 explored how infants use their innate speech perception mechanisms to learn vocabulary and build language. The study examined 48 eight-month-old infants and documented their innate statistical language learning processes. Saffran and colleagues familiarized the infants with connected speech streams of nonsense words (e.g. [*bidakupadotigolabubidak*]) with transitional properties marking word boundaries (e.g. [*bida*] was acoustically separate from [*kupa*]). Following the exposure to the nonsense words, the researchers assessed the infants' abilities to differentiate between the

familiar nonsense words and parts of nonsense words by measuring their tendency to listen longer to unfamiliar stimuli, in this case, the part-words. Findings indicated that infants possess early powerful language learning mechanisms that allow them to statistically categorize familiar connected speech stimuli and identify breaks, or boundaries, between words. This statistical learning mechanism is a marriage between innate and learned knowledge, where infants' natural capabilities thrive on meaningful spoken language input, allowing the use of both statistical learning and speech perception skills to combine for rapid language acquisition. Rich input (in this case, an abundance of linguistic sounds) must be accessible in order for infants to tap into this formidable language learning mechanism (Saffran, 2003). In other words, meaningful acoustic experience is vital for early language and vocabulary learning to take place. These powerful learning mechanisms illuminate the importance of early access to auditory information for fundamental spoken language skill-building, including recognizing, learning, and using speech stimuli for the building of lexical knowledge.

1.1.2 Early Vocabulary Development in TH children

Children who are typically-developing are primed to listen and develop spoken vocabulary and language within the first few years of life. In general, infants build upon their auditory experiences in the first few months of life by responding to and playing with speech sounds. In the next few months, children progress from sound play to word comprehension and babble-like imitations. In the last months before a child's first birthday, understanding of words has expanded to most common items. By about 12 months old, most children achieve their first word productions. Following their first words productions, children continue to build their lexical knowledge and express more words. Around an average of 18 months, most children

exhibit a rapid increase in expressive vocabulary development, sometimes referred to as a *vocabulary spurt* or *naming explosion* in the literature (Bloom, 1976; Dromi, 1987; McCarthy, 1954; Nelson, 1973; Reznick & Goldfield, 1992). Alternative viewpoints argue the true existence of this vocabulary spurt (Bloom, 2000; Granger & Brent, 2004), endorsing the idea of great variation in development. Despite the ranges in lexical achievement, children who are typically developing are primed to listen and develop spoken vocabulary and language within the first few years of life and tend to achieve lexical benchmarks or milestones within average age ranges. Table 1.1.1, adapted from a 2015 National Institute on Deafness and other Communication Disorders [NIDCD] hearing checklist, details receptive and expressive vocabulary milestones during the first three years of life.

Table 1.1.1 Receptive and expressive vocabulary milestones adapted from NIDCD (2015).

Typical Age Range	Receptive milestone	Expressive milestone
0 – 3 months	Reacts to loud sounds, Calms to caregivers' voices	Coos and makes pleasure sounds, Special cries for specific needs
4 – 6 months	Follows sounds with eyes, Responds to changes in tone of voice	Babbles in a speech-like way, Uses /p/, /b/, and /m/ phonemes
7 – 12 months	Understands words for common items, Responds to requests	Imitation and reduplicated babbling, Produces 1-2 words
13 – 24 months	Points to body parts when asked, Follows simple directions	Rapid word learning and production, Produces 1-2-word combinations
25 – 36 months	Understands new words quickly, Follows 2-part directions	Uses 2-3-word phrases and questions, Produces intelligible speech

To achieve these vocabulary milestones, children who are typically developing primarily use three instinctive strategies for novel word-learning, including joint attention (e.g. Tomasello & Todd, 1983; Tomasello, 1995), fast mapping (e.g. Carey & Bartlett, 1978; McLaughlin, 1998), and over-hearing (e.g. Akhtar, 2005; Akhtar, Jipson, & Callanan, 1998; 2001; Gampe, Liebal, & Tomasello, 2012).

The earliest observed word-learning mechanism is joint attention. Joint attention between a caregiver and child refers to a shared period of sustained focus on each other and a referent, usually an object or event, while the caregiver provides a spoken label for the referent (Tomasello & Todd, 1983; Tomasello, 1995). As described in Table 1.1.1 above, infants begin to follow sound with their eyes by about four to six months of age. A few months after this foundational receptive milestone is reached, children begin engaging in joint attention, emerging with the skill between eight and twelve months (Johnson, Ok, & Liu, 2007; Woodward, 2003). Over time, children learn to respond consistently to caregivers' joint attention intentions and initiate their own joint attention opportunities using gaze, head-turning, or pointing, solidifying the skill by 18 months (Bertenthal & Boyer, 2015; Brooks and Meltzoff, 2008).

Fast mapping is another of the primary processes by which a child acquires vocabulary. This word-learning mechanism occurs when a child is exposed only once or twice to an unknown word and makes a quick connection to the word's referent, usually a real object or a picture. The exposure allows the child to draw an inferred meaning of the novel word, subsequently making the connection between the word and the new understanding of its referent, resulting in a newly learned word (McLaughlin, 1998). Many studies have demonstrated that children retain knowledge of words learned through fast-mapping weeks and even months later

(e.g. Carey & Bartlett, 1978; Gershkoff-Stowe & Hahn, 2007; Heibeck & Markman, 1985). Typically-developing children as young as 13 months of age have been reported to learn and maintain new vocabulary words through fast-mapping (Kay-Raining Bird & Chapman, 1998; Woodward, Markman, & Fitzsimmons, 1994).

A third word-learning mechanism is exposure to novel words through over-hearing. Over-hearing as a vocabulary acquisition process refers to the learning of unknown words through external interactions in which a child is not directly involved, given that the child is attending and within hearing range of the third-party interaction. Formative studies by Akhtar, Jipson, and Callanan (1998; 2001) demonstrated the ability of children to learn vocabulary words through listening to others' conversations with similar efficiency as to learning through direct interactions. Further work by Akhtar (2005) indicated the remarkable abilities of children at two-years of age to effectively use overhearing to learn new words in multiple contexts, including when distracting activities were present and when novel words were introduced through directives, rather than through explicit labeling. The efficacy of this sophisticated word-learning mechanism has been more recently observed in toddlers as young as 18 months (Gampe et al., 2012).

Each of these word-learning strategies are dependent on a child's ability to hear speech. Collectively, the strategies facilitate the achievement of vocabulary milestones as previously described for typically-developing children. Children who demonstrate large and robust vocabularies in their early years are more likely to later demonstrate better linguistic and cognitive outcomes as compared to children with smaller and less robust vocabularies. A longitudinal study by Marchman & Fernald (2008) examined this connection between early

9

achievement and later outcomes over a six-year time period. In their study, children's

vocabulary sizes and speeds of spoken word recognition were tested at 25 months. Then, the

same children were tested again at 8 years with a variety of standardized tests, including

vocabulary, language, and cognitive assessments. The findings indicate that both the speed of

recognition and size of vocabularies at just over two years of age were uniquely and positively

related to their later linguistic and cognitive performance.

1.2   Development of Children who are d/hh

Children who have congenital hearing loss do not develop auditory systems or spoken

language skills in the same way as their TH peers. For this reason, an extensive field of literature

exists to determine the unique ways in which children who are d/hh develop, learn, and reach

milestones related to their hearing peers. The following sections will review auditory and

spoken language development for children who were born with hearing loss.

1.2.1 Early Auditory Development in Children who are d/hh

For children who are congenitally d/hh born to hearing families using spoken language,

access to auditory input is an immediate concern. Because the auditory system develops in utero,

children who are born with sensorineural hearing loss are likely to have experienced minimal and

degraded auditory input during gestational auditory learning opportunities. Graven and Browne

(2008) remind us that the auditory system begins development in utero, with especially critical

periods of neurosensory development between about 25 weeks' gestation and about five or six

months post-birth. Further, the first 1000 days in an infant's life are considered a critical period

of brain development (Leadsom, Field, Burstow, & Lucas, 2013; Shonkoff, 2017). In infancy,

the human brain is capable of making more than one million new neural connections per second

10

(Shonkoff, 2017). This formative period of rapid proliferation is unmatched at any other age in human life. During this critical time for brain growth, the neural connections are not only developing at a rapid rate, but they are also strengthened by meaningful input such as rich language interactions with a caregiver.

In the absence of linguistic input, the capabilities of the brain remain untapped, thus leaving the vast majority of the developing brain underused, with diminished capacity for learning (Lore, Ladner, & Suskind, 2018). In the case of audiologic brain development, the absence of input leads to reorganization of unused areas. Areas in the brain which had been reserved for audiologic interpretation can be cortically reorganized to process other sensory information, such as vision or somasensation (Gordon, Wong, Valero, Jewell, Yoo, & Papsin, 2011; Sharma, Campbell, & Cardon, 2015). In a series of studies by Sharma and colleagues (2002; 2007; 2009; 2015), children who were d/hh and given access to auditory input via assistive technology prior to three years of age developed auditory systems that were most similar to children who were TH. The same studies provide evidence to substantiate seven years of age as the end of the sensitive period of auditory cortical development, and as such, implantation after this age results in significantly reduced abilities to process auditory input from assistive technology.

The absence of adequate access to meaningful auditory input also leads to missed opportunities for early statistical learning and categorical speech perception as described previously (e.g. Eimas, 1974; Moon et al., 2013). A study by Gordon and colleagues (2011) demonstrates that the auditory nerve can develop independently from input for a short period of time, but as months go by without auditory input, reorganization of the auditory brain,

11

particularly in the thalamo-cortical area, begins to occur. When cortical reorganization ensues, the synapses reserved for auditory input interpretation begin to adjust intent and restructure to specify interpretation of input from other sensory areas. In order to capitalize on the auditory brain at its peak, early screening, amplification, and intervention services should be considered for children who are d/hh.

With the implementation of early hearing detection and intervention (EHDI) legislation, including universal newborn hearing screening (NBHS) policies, the number of early identified children who are d/hh has risen dramatically in the past three decades (NIDCD, 2017). Prior to federal NBHS programs established in the United States in 1999, hospitals screened fewer than ten percent of newborn babies for hearing loss. This lack of initial assessment led to an annual 50% average of congenitally d/hh children going unidentified and without intervention until three years of age or later. Today, with EHDI and NBHS in place, only 2% of babies per year go without newborn hearing screenings, leading to earlier identification, earlier amplification, and earlier language interventions (NIDCD, 2017). EHDI 1-3-6 guidelines sanction screening for hearing loss by at most 1 month of age, diagnosis by 3 months, and interventions in place by 6 months (JCIH, 2007). In a Hearing Screening and Follow-up Survey from the 2017 National CDC EHDI data, 97.1% of infants were screened prior to 1 month of age, with 75.4% receiving their diagnosis as early as three months of age, and 66.7% receiving early intervention services before six months of age (CDC, 2019b). These improved figures for identification, amplification, and intervention give children earlier opportunities to capitalize on critical periods of neurosensory development. Stricter guidelines of 1-2-3 (screening for hearing loss by 1 month of age, identification by 2 months, and interventions in place by 3 months) have been suggested for

states currently meeting 1-3-6 goals to further improve early access to auditory input, as well as to increase time capitalizing on early cognitive processes for auditory and linguistic learning (Joint Committee on Infant Hearing [JCIH], 2019).

As mentioned above, TH children as young as eight months old can be observed using acoustic input to categorize phonemes and build lexical knowledge. For children who are d/hh, the key to categorizing phonemic information—rich acoustic input—is missing at an early age. This means that while children who are d/hh are cognitively unimpaired, and thus should be able to use the same learning mechanisms as children who are TH, they require intervention including early auditory access and explicit listening and spoken language instruction to be able to do so. In today's technologically advanced world, earlier screening and identification leads to earlier amplification. More children with hearing loss are identified today than ever before, and thus are earlier accessing sound through assistive listening devices, such as hearing aids and cochlear implants (CDC, 2019b). When appropriately fit by an audiologist, hearing aids and cochlear implants grant users with mild to profound hearing loss access to speech sounds that would otherwise not be available.

1.2.2 Early Vocabulary Development in Children who are d/hh

As mentioned previously, children who are d/hh are starting out at a disadvantage in terms of time spent learning through listening. However, when children who are d/hh are given early access to auditory input through amplification or implantation, reports have shown that children are more likely to successfully use innate word-learning strategies, such as joint attention. In a study using the Intermodal Preferential Looking Paradigm (IPLP), Houston, Stewart, Moberly, Hollich and Miyamoto (2012) discovered that children who are implanted

prior to 12 months were able to learn words in a more typical way by tuning into word-object pairs, later than milestone ranges from TH peers, but using the same mechanism through joint attention. However, children who were implanted after 18 months were unable to learn words in this way, adding evidence to the need for early intervention for vocabulary growth. This study adds perspective to the series of studies by Sharma and colleagues (2002; 2007; 2009; 2015) described above, which indicate that the sensitive period for auditory cortical development may last as long as seven years after birth. Houston and colleagues' work adds perspective to this sensitive period, marking cochlear implantation prior to one year as the ideal milestone for increased capitalization of early auditory cortical development which support later use of typical auditory word-learning strategies.

Even with the documented improvements in early identification and assistive listening technology, children who are d/hh continue to demonstrate fewer total quantities of known vocabulary words when compared to their TH peers (e.g. Davidson, Geers, & Nicholas, 2014; Ganek, McConkey-Robbins, & Niparko, 2012; Hayes, Geers, Treiman, & Moog, 2009; Nott, Cowan, Brown, & Wigglesworth, 2009; Yoshinaga-Itano, Sedey, Wiggin, & Chung, 2017). When early intervention was in place, such as in a 2009 study by Hayes and colleagues, children who wore cochlear implants and received early educational services were still shown to fall behind their TH peers. Hayes and colleagues investigated a school-aged group of children who were d/hh and found that they followed a somewhat similar receptive vocabulary learning trajectory as children who are TH, but often times had less steep, slower growth than their hearing peers. Although the children were shown to make steady progress in receptive vocabulary growth, their outcomes were still below the low average range of their peers, topping

14

out at about 80, where the low average range starts at a standard score of 85. Importantly and positively, Hayes and colleagues used hierarchical linear modeling to predict that when children are implanted before 12 months, they have the best chance to close this performance gap by making more than a year's progress in a year's time, thus eventually catching up to their peers and demonstrating age-appropriate vocabulary skills within the average range.

Of great interest is the growth of very young children who are d/hh. Another 2009 study on vocabulary learning by Nott and colleagues investigated children with hearing loss under three years of age. Nott and colleagues compared vocabulary achievement outcomes of both children who were TH and those who were d/hh to determine the difference in acquisition milestones between the two groups. The study included 24 children with severe to profound hearing loss and 16 who were TH, documenting their lexical milestones such as their first 50 and first 100 single words. All children who were d/hh were fit with amplification devices prior to 30 months old. Parents of the children in each group kept detailed records of their child's word-learning progress in daily diaries, using the Diary of Early Language (Di-El). Nott and colleagues used independent two-sample *t* tests to analyze group means for children who were d/hh and children who were TH. Results indicated that children who were d/hh required an average of 2 more months than TH children to learn their first 50 expressive words. Nott and colleagues reported that the gap between the two groups continued to grow, with a 3.8 month difference in time taken to learn 100 words.

A more recent study also investigated vocabulary outcomes in very young children who were d/hh, focusing on expressive development and the influence of meeting EHDI's 1-3-6 guidelines (JCIH, 2007; 2019). As described previously, EHDI 1-3-6 guidelines have stipulated

15

early goals for screening, identification, and intervention together to create an earlier, more ideal timeline for children who are d/hh to gain auditory access and strengthen vocabulary and language connections in their young, growing brains. Yoshinaga-Itano and colleagues (2017) used regression analysis to investigate the effect of meeting the EHDI 1-3-6 guidelines on expressive vocabulary outcomes. The findings from Yoshinaga-Itano and colleagues' study revealed significantly higher expressive vocabulary scores for children who met the 1-3-6 guidelines compared to those who did not. Additional factors with positive influence on vocabulary outcomes included less hearing loss, the absence of additional disabilities, having mothers with higher education, and having parents who were also d/hh. With these influential variables in place, children who are d/hh have greater chances of achieving higher quantities of vocabulary as compared to when the guidelines are not met, and the variables are not in place. Yoshinaga-Itano and colleagues also examined participants' vocabulary sizes relative to their chronological age by plotting average vocabulary quotients across chronological age from 10 to 40 months. Results showed that vocabulary sizes between 10 and 40 months decrease, widening the gap between chronological age (what is typical at a given age) and vocabulary quotient (what participants were achieving at a given age). The gap was shown to be greater for those who did not meet 1-3-6 guidelines. In order for children who are d/hh to close the gap between their growth trajectories and their peers', steep growth must be achieved. Ideally, it must be achieved as early as possible. Understanding the factors that contribute to vocabulary growth in young populations is critical for supporting improved outcomes and lessening the widening gap as demonstrated by the work of Yoshinaga-Itano and colleagues.

1.3 Factors Contributing to Vocabulary Outcomes

There are several variables that have been shown to affect vocabulary and language outcomes in children who are d/hh, including, but not limited to: age at hearing loss identification or diagnosis (e.g., Apuzzo & Yoshinaga-Itano, 1995; Meinzen-Derr, Sheldon, Grether, Altaye, Smith, Choo, & Wiley, 2018; Yoshinaga-Itano, Sedey, Coulter, & Mehl, 1998), age at first amplification (e.g., Ching, 2015; Ching, Dillon, Marnane, Hou, Day, Seeto, & Yeh, 2013;), age at cochlear implantation for those with severe to profound hearing losses (e.g., Boons et al., 2012; Geers, Nicholas, Tobey & Davidson, 2016; Hayes et al., 2009; Nicholas & Geers, 2007; 2013), sequential implantation for those with moderate to severe hearing losses (e.g., Davidson, Geers, Uchanski & Firszt, 2019), age at enrollment in educational intervention services (e.g., Moeller, 2000; Vohr, Jodoin-Krauzyk, Tucker, Johnson, Topol, & Ahlgren, 2008; Vohr, Jodoin-Krauzyk, Tucker, Topol, Johnson, Ahlgren, & Pierre, 2011), nonverbal intelligence quotient (e.g., Geers, Moog, Biedenstein, Brenner, & Hayes, 2009; Geers, Strube, Tobey, Pisoni & Moog, 2011), assistive listening device wear time (e.g., Tomblin, Oleson, Ambrose, Walker, & Moeller, 2014), speech perception abilities (e.g., Geers, et al., 2011; 2016), level of mother's education (e.g., Ching, 2015; Ching et al., 2013; Cuda, Murri, Guerzoni, Fabrizi, & Mariani, 2014; Szagun & Stumper, 2012; Walker, Redfern, & Oleson, 2019), verbal working memory skills (e.g., Geers et al., 2011, Harris, Kronenberger, Gao, Hoen, Miyamoto, & Pisoni, 2013; Pisoni, Kronenberger, Roman, & Geers, 2011), and presence of additional diagnoses (e.g., Boons et al., 2012; Ching et al., 2013; Vohr et al., 2011).

Many of these variables are not independent of one another. Some are difficult to measure in early-intervention-aged populations due to the challenges of conducting behavioral studies with infants or toddlers. There are four main variables of interest for the present study

including, 1) age at identification, 2) level of mother's education, 3) additional diagnoses, and 4) frequency of intervention. The following paragraphs will address each variable of interest.

1.3.1 Age at Identification

Age at identification is often closely associated with age at amplification or first hearing aid, as well as age at enrollment in intervention services. For example, the age at which a child is identified as d/hh marks the start of their journey in intervention. This is the first age point which prompts caregivers to then decide on language input, amplification devices, and intervention services. The goal of EHDI legislation has been to assure that all infants who are d/hh are identified as early as possible, due to early sensitive periods of development. Current EHDI guidelines emphasize initial audiologic screening by 1 month and identification of hearing status by 3 months. The goal is then to have amplification and intervention in place by 6 months (JCIH, 2007). A recent statement from the Joint Committee on Infant Hearing (2019) proposed that states which currently meet the 1-3-6 guidelines strive for an even earlier timeline: 1-2-3, with screening by 1 month, identification by 2, and intervention in place by 3 months. The push for earlier guidelines highlights the importance of receiving an evaluation and diagnosis from an audiologist as soon as possible. With later identification, more time for learning is missed in critical periods of development—times when the brain is most flexible, waiting for input to shape and strengthen its synaptic connections, which in turn shape how the brain allots its resources and communicates with itself. Given this information, it is not surprising that children who are identified with hearing loss at earlier ages typically perform better on vocabulary and language tests when compared to those with similar characteristics who were identified later (Apuzzo & Yoshinaga-Itano, 1995; Meinzen-Derr et al., 2018; Yoshinaga-Itano et al., 1998).

1.3.2 Mother's Highest Level of Education

As described in the Introduction, children are dependent on auditory input for spoken language growth. The most important auditory input a child can receive for linguistic growth is speech and language input. In homes across the world, very young children are spending the majority of their waking hours with their mother or another caregiver. These waking moments are learning opportunities for young children, and the kind of input a child receives affects his or her learning. In the field of typical child development, the relationship between maternal education and child language learning is well-documented. The differences in mothers' levels of education are often associated with variation in quantity and quality of linguistic input from mother to child (Dollaghan, Campbell, Paradise, Feldman, Jonosky, Pitcairn, & Kurs-Lasky, 1999; Hart & Risley, 1995; Hoff, 2003; Huttenlocher, Waterfall, Vasilyeva, Vevea, & Hedges, 2007), which in turn, influence the child's language development (Hoff, 2003, 2006; Huttenlocher, Waterfall, Vasilyeva, Vevea, & Hedges, 2010; Rowe, 2012; Song, Spier, & Tamis-LeMonda, 2013) . For children who are d/hh, a significant influence of maternal education on child language outcomes has also been observed (e.g. Cuda et al., 2014; Szagun & Stumper, 2012; Walker et al., 2019).

1.3.3 Additional Diagnoses

It is estimated that 40 – 50% of children who are identified as d/hh also have an additional diagnosis (Bruce & Borders, 2015; Chilosi, Comparini, Scusa, Berrettini, Forli, Battini, & Cioni, 2010; Guardino & Cannon, 2015; Office of Research Support and International Affairs, 2014). Additional diagnoses, whether neurodevelopmental, craniofacial, or speech/language disorders, intensify a child's everyday life. An additional diagnosis may interfere with processing or learning, with oral motor skills, or even with the ability to attend

intervention on a regular basis. Even when an additional diagnosis does not affect cognition or ability to acquire speech and language skills, the diagnosed child may be receiving additional treatments or intervention services that require time in addition to d/hh services, he may be in and out of the hospital, and he may be learning to live in a world that caters to typically-developing people. In many cases, additional concerns compete with a dual-diagnosed child's attention and/or ability to learn at the increased rate which is needed to catch up to his TH peers. As time goes on, the gap between TH peers and a dual-diagnosed child widens due to additional concerns continuing to occur in the child's life. Several studies have documented the significant negative effect that an additional diagnosis has on vocabulary and language outcomes (e.g., Boons et al., 2012; Ching et al., 2013; Vohr et al., 2011).

1.3.4 Hours of Intervention

Frequency, dosage, and hours of instructional intervention all describe a variable is in need of more investigation. Children who are d/hh and learning spoken language require explicit instruction to learn to listen, process important auditory input, and acquire vocabulary. This explicit instruction occurs through specialized intervention implemented by a certified teacher of the deaf or speech-language pathologist specializing in LSL. A recent publication by Geers, Moog, and Rudge (2019) reported the results of one of the only studies that has investigated the influence of hours of intervention on spoken language outcomes for children who are d/hh. The longitudinal study followed 50 children and investigated how their hours of early intervention (ages birth to three years) influenced later language outcomes in both preschool (ages four to six years) and in elementary school (ages eight to 14 years). Both preschoolers and elementary aged students benefited linguistically from higher quantities of instructional hours in early

intervention. Students who demonstrated poorer speech perception skills during preschool exhibited the most benefit from greater amounts of early intervention, achieving the most gain in language outcomes compared to their preschool scores. More work is needed to explore the influence of hours of intervention on expressive vocabulary growth trajectories within the birth to three population.

1.4 Summary of Need

A number of studies have demonstrated that children who are d/hh are at a lexical disadvantage, presenting with smaller productive lexicons, when compared with age-matched TH children (e.g., Nott et al., 2009; Yoshinaga-Itano et al., 2017). Much of what is known about expressive vocabulary in the young d/hh population is limited to achievement studies with one to two observations of lexical knowledge. No known studies have investigated the trajectories of expressive vocabulary growth in children who are d/hh between the ages of birth to three, nor the possible contribution of intervention services in rate of development. Thus, there was a need for a longitudinal study investigating repeated measures of expressive vocabulary growth and factors that influence the growth with the youngest population of children who are d/hh. The present study addressed the need for investigation of a large number of young participants who had repeated measures of vocabulary using a robust measure of analysis. Additionally, there was a need for a study which controlled for type of intervention communication modality, and audiologic management, while also investigating factors with potential predictive value. Thus, the present study was conducted.

This dissertation study examined and analyzed expressive vocabulary growth rates in early intervention-aged children who are d/hh and investigated the factors that contributed to

their rates of lexical development. This study used a retrospective, longitudinal approach to

model growth curves with a robust statistical analysis—hierarchical linear modeling—and

identified potential predictors of the growth over time spent in early intervention.

Chapter 2: Study

The present study aimed to contribute to the literature on expressive vocabulary growth trajectories in very young children who are deaf or hard of hearing, as well as to the literature on factors affecting expressive vocabulary development in the same population. Previous studies, as described earlier, focused mainly on vocabulary achievement outcomes as opposed to trajectories of early expressive growth and factors influencing observed growth rate. Thus, to add to what is known, the primary goal of this study was to explore the expressive vocabulary growth rate of children ages birth to three years, who are d/hh. A secondary goal was to investigate hours of direct instruction received during early intervention as a factor that may contribute to the trajectories of expressive vocabulary growth in young children who are d/hh. To address each of these goals, two research questions were posed:

1. How quickly do very young children who are deaf or hard of hearing develop new expressive vocabulary?
2. How do hours of instruction received in an early intervention program before age three contribute to differences in early expressive vocabulary growth?

The following paragraphs describe the specific methods and analyses conducted to achieve the goals of the study.

2.1 Participants

The participant sample consisted of 105 children with degrees of hearing ranging from mild to profound loss. All participants were recruited from the same specialized early intervention program for children who are d/hh whose families had chosen listening and spoken language (LSL). The children were followed longitudinally from their initiation of the program until they aged out of early intervention at three years of age. Each participant met the following criteria: a) enrolled in the early intervention program between the years 2002 and 2019, b) had been given two or more expressive vocabulary assessments over the course of time spent in the program, and c) were 37 months or younger at the time of each vocabulary assessment. Early intervention profiles were compiled on each of the 105 participants, detailing the following: 1) age at identification of hearing loss, 2) age at amplification via first assistive listening device, 3) age at entry to the early intervention program, 4) total hours of intervention received over the course of time spent in the program, 5) presence or absence of additional diagnoses, and 5) repeated measures of expressive vocabulary via the MacArthur-Bates Communicative Development Inventory (Fenson, Marchman, Thal, Dale, Reznick, & Bates, 2007).

Data were obtained retrospectively through the early intervention program's educational and audiologic databases. All participants received individualized and group therapy session during their time in the early intervention program, including auditory, vocabulary, and syntactic instruction. Tables 2.1.1 and 2.1.2 further describe the participants' characteristics.

Table 2.1.1 Participant Education and Intervention Characteristics

	Mean	St. Dev.	Range
Age at identification (months)	6.03	7.79	0.3 - 32
Age at amplification (months)	8.03	7.72	0.5 – 32
Age at entry to early intervention program (months)	10.28	9.29	0.5 – 32
Frequency of early intervention (hours)	396.20	169.25	52 – 831
Mother's highest level of education (years)	16.00	1.98	12 – 20

Table 2.1.2 Participant Demographic and Audiologic Characteristics

Characteristic	Categorical Level	Frequency	%
Gender	Male	53	50
	Female	53	50
Additional Neurodevelopmental Diagnosis	Yes	27	26
	No	78	74
Assistive Listening Devices	None	2	1.9
	BAHA	13	12.4
	1 Digital Hearing Aid	8	7.6
	2 Digital Hearing Aids	45	42.9
	Bimodal	7	6.7
	1 Cochlear Implant	3	2.9
	2 Cochlear Implants	27	25.7
Degree of Hearing Loss	Unilateral	15	14.3
	Mild	15	14.3
	Moderate	20	19
	Moderately Severe	14	13.3
	Severe	5	4.8
	Profound	36	34.3

2.2 Materials

The outcome variable of interest—expressive vocabulary scores over time spent in an early intervention program—was measured by a norm-referenced tool, the MacArthur-Bates Communicative Development Inventories [MB-CDI] (Fenson, Dale, Campbell, Colborn, Kurs-Lasky, & Rockette, 1994; Fenson et al., 2007). The MB-CDI is a valid and reliable instrument designed to measure the quantity of known receptive and expressive vocabulary (Thal, Desjardin, & Eisenberg, 2007). It consists of sets of checklists with prespecified words, as well as phrases and sentences. Two MB-CDI checklist forms were routinely used by the recruitment site at the time of the study and had been in use for over 17 years as a regular assessment of students' vocabulary achievement while enrolled in the early intervention program. The first form, *MB-CDI: Words and Gestures*, included a total of 396 words, and was normed on typically developing infants and toddlers aged 8 to 18 months. The second form, *MB-CDI: Words and Sentences*, included a total of 680 words and was normed on typically developing children aged 16 to 30 months. Both forms have been suggested for use with older children who are delayed or atypically developing (Fenson et al., 2007).

Participants were also rated on their ability to perceive speech as a part of regular audiologic testing at the early intervention recruitment site. Each participant received formal speech perception testing before age 37 months. The battery of speech perception is described in the following list:

1. *The Ling Six Sound Test [Ling 6]* (Ling, 1976; 1989). The Ling 6 test assesses the most basic level of speech sound perception, detection, with six speech sounds: *oo, ee, ah, s, sh, and m.* These six sounds broadly represent the frequencies of conversational speech from 250 – 8000 Hz, targeting low, middle, and high frequency

speech sounds. Responses to sounds in this test, while not diagnostic, give

information about a child's access to sounds across the speech spectrum. This test can

also be used to assess discrimination and identification at the speech sound level.

2. *The CID Early Speech Perception Test [ESP]* (Moog & Geers, 1990; 2012). The ESP

    test assesses discrimination and identification of single words in a closed-set task with

    pictures representing each word. The words included in the test were selected to be

    familiar to children who are d/hh by age six and suitable for pictorial representation.

    Additionally, the participant must demonstrate a correct response to all words in an

    auditory-visual task before the test can be administered in an auditory-only condition.

    A low-verbal version of the test assesses spondee word discrimination, while the

    standard version assesses identification of monosyllable words differing in vowels.

3. *The Word Intelligibility by Picture Identification Test [WIPI]* (Ross & Lerman,

    1970). The WIPI assesses identification of words differing in consonants in a closed-

    set task with pictures representing each word. The words included in this test may or

    may not be familiar to the participant, as vocabulary knowledge is not assessed in

    auditory-visual conditions prior to the administration of the test.

4. *Multisyllabic Lexical Neighborhood Test [MLNT] and Lexical Neighborhood Test*

    [LNT] (Kirk, Pisoni, & Osberger, 1995). The MLNT and LNT assess the open-set

    identification of words with two or more syllables (MLNT) or with single syllables

    (LNT) by requiring the participant to imitate the word after stimulus presentation.

    Both tests had a lexically easy list and a lexically hard list, respectively containing

    words which occur often and have few phonemic neighbors, or words which occur

less often and have many phonemic neighbors. Word stimuli included in the test were selected to be familiar to children with limited lexicons.

2.3 Procedures

To achieve the goals of this study, multiple points of longitudinal data were collected on all 105 participants using the early intervention program's educational and audiologic databases. Each participant contributed repeated measures of expressive vocabulary scores from MB-CDI assessments, with a total of 417 assessments across the 105 participants.

Teachers of the Deaf working at the early intervention program routinely measured all children's lexicons with the MB-CDI early assessment form, *MB-CDI: Words and Gestures*, regardless of biological age. After the student achieved near total expressive production of all words on the first form, the second form, *MB-CDI: Words and Sentences*, was introduced as a measure of the number of words expressively known. Teachers partnered with the student's caregiver to complete the forms on a semi-regular basis over the course of a student's enrollment in the on-site portion of the early intervention program. MB-CDI outcome assessments were collected, on average, every 3 months beginning as early as 17 months until the end of the early intervention program, after a student's third birthday, culminating in an average of 4 assessments each by completion of the program. Although both forms offer additional information related to gestures, phrases, and sentence use, only the expressive vocabulary portion of each form was calculated for the purposes of addressing the research questions of this study. Table 2.3.1 details the participants' achievements and attributes related to the MB-CDI Instrumentation.

Table 2.3.1 Participant outcomes related to the MacArthur-Bates Communicative Development Inventories

	Mean	St. Dev.	Range
Age at first expressive vocabulary assessment (months)	22.90	4.05	17 - 32
Age at last expressive vocabulary assessment (months)	32.33	3.77	21 – 37
Number of assessments	4.12	1.81	2 – 10
Frequency of assessments (months)	3.19	2.05	1 – 13
Number of words produced at first assessment	52.73	86.99	0 – 627
Number of words produced at last assessment	289.39	172.30	10 – 665

The early intervention program's staff of onsite pediatric audiologists administered a variety of speech perception tests to all students of the program as a routine part of audiologic care. Each participant was administered the speech perception test that was most appropriate for the child's developmental and auditory skill levels, based on the hierarchy of auditory skill development: detection, discrimination and pattern perception, identification, and comprehension (Erber, 1982; Geers, 1994). Tests were performed individually on each child in sound-proof audiologic booths by an audiologist and an audiologist assistant. If the child wore one or two assistive listening devices, the devices were worn during the testing to compile aided speech perception results. Due to the low working vocabularies of the young children in this study, many children did not receive speech perception testing until the end of their time in the early intervention program. For this reason, only the latest speech perception measure in early intervention, or the score obtained closest to age 37 months, was recorded. Table 2.3.2 details the

scaled scoring of each speech perception score based on the type and hierarchical complexity of reported tests.

Table 2.3.2 Speech perception scores ranked by order of auditory skill complexity

Speech Perception Test	Scaled Score
The Ling Six Sound Test	0 – 100
The CID Early Speech Perception Test – Spondees (ESP-Spondees)	101 –200
The CID Early Speech Perception Test – Monosyllables (ESP-Monosyllables)	201 – 300
The Word Intelligibility by Picture Identification (WIPI)	301 – 400
Multisyllabic Lexical Neighborhood Test – Easy Word List (MLNT-E)	401 – 500
Multisyllabic Lexical Neighborhood Test – Hard Word List (MLNT-H)	501 – 600
Lexical Neighborhood Test – Easy Word List (LNT-E)	601 – 700
Lexical Neighborhood Test – Hard Word List (LNT-H)	701 – 800

On average, participants achieved a scaled speech perception score of 436.23 (SD = 201.51).

2.3.1 Statistical Analyses

Traditional regression analysis (i.e. repeated measures ANOVA) does not allow for violations of the following assumptions in the data: 1) independence, 2) homoscedasticity, and 3) consistent intervals, and 4) linearity. The nested dataset that was compiled to address the previously mentioned research questions violated each of these assumptions. Because the data contained multiple expressive vocabulary observations of the same individual, those individuals had idiosyncrasies that affect every one of their observations, leading to dependencies in the

data. Additionally, the data were nested and clustered, meaning that there were clusters of students and clusters of score observations. The 417 observations were nested within the 105 students, which led to different levels of variance between groups and a violation of homoskedasticity. The data also contained differences between each time of observation for each student, as well as varying numbers of measures given to each student. Further, the shape of the data was unknown to be linear or quadratic in nature. HLM, unlike traditional regression analysis, accounts for each of these points, allowing for dependencies in the data, heteroskedasticity, flexibility in the number and spacing of measurement in outcome assessments, and non-linearity. Importantly, HLM allows for the simultaneous measurement of growth over time in an outcome of interest (e.g. expressive vocabulary) at both an individual time-varying outcome occasions level and a characteristic level to explain the variability in outcomes (Willett, Singer, & Martin, 1998).

Analyses were conducted using SPSS-24 (IBM, 2016) and HLM 8 (Raudenbush, Bryk, Cheong, & Congdon, 2019). To investigate the growth of the children across their vocabulary assessments, the nested data was placed into a two-level combined model, where level 1 accounted for the vocabulary assessments over time spent in the early intervention program and level 2 accounted for the variables that contributed to the changes in vocabulary outcomes over time. The level 1 component of the model resembled an ordinary least squares regression (OLS) model and described the individual growth rate with a time-varying predictor variable of age in months at vocabulary measure. The parameter estimate of slope from level 1 was then treated as an outcome in the next level of the model, level 2. The level 2 component of the model explained the variation in expressive vocabulary growth over time with respect to the predicting factors

31

included in the model. Predicting factors were selected because past research indicates their effect on spoken language and vocabulary growth of children who are deaf or hard of hearing, including level of maternal education, presence or absence of an additional diagnoses, and age at hearing loss identification. As previously described in the Introduction, the frequency of intervention, as measured by the hours that each student who is d/hh receives in LSL-specific intervention, had been shown to affect later spoken vocabulary and language outcomes in late youth (Geers et al., 2019). However, the effect of frequency of intervention had not yet been explored with a younger population, such as one that has been identified early and received intervention prior to three years of age. Thus, hours of intervention received was a variable of interest in the current study's analysis. Each of these predicting variables were entered into the analysis centered at their grand means to investigate their relationship with the outcome variable, the growth of expressive vocabulary scores.

2.4 Results

The purpose of this study was to investigate trajectories of vocabulary growth in children who were d/hh between the ages 17 to 37 months. An additional goal was to examine how hours of early intervention contribute to individual differences in growth trajectories. Correlational analyses were conducted in SPSS v.24 to examine relationships between participants' demographic variables. It was noted that the four variables of interest (maternal education, hours of intervention, age at identification, and additional diagnosis) were not significantly correlated with each other. Table 2.4.1 displays correlation coefficients for all collected variables, including the above noted four variables of interest, as well as age enrolled in early intervention, age received first hearing aid, age received first cochlear implant, speech perception at time closest to

36 months, and number of words produced at last MB-CDI. Results from the correlational

analyses statistically supported the independent inclusion of the

four variables in the subsequent analyses.

Table 2.4.1 Correlations for all descriptive variables, $N = 105$

	Maternal Education	Hours of EI	Add'l Diag.	Age at ID	Age at EI	Age at HA	Age at CI	Speech Perc.	Last CDI outcome
Maternal Education	1								
Hours of EI	.019	1							
Additional Diagnosis	.106	-.150	1						
Age at ID	.014	-.173	-.003	1					
Age at EI	.084	**-.239***	.021	**.707****	1				
Age at HA	.054	**-.213***	.090	**.928****	**.702****	1			
Age at CI	.003	.021	-.005	**.617****	.294	**.635****	1		
Speech Perception	.038	**.355****	-.004	.023	.019	.043	.171	1	
Last CDI outcome	.012	**.330****	-.097	**-.231***	**-.281****	**-.201***	**-.344***	**.318****	1

Note. CDI = MacArthur Bates Communicative Development Inventory; CI = cochlear implant; EI = early intervention; HA = hearing aid; ID = identification; HA = hearing aid; WP = words produced.
* indicates significance at the $p<0.05$ level, **indicates significance at the $p<0.01$ level.

To explore the expressive vocabulary growth of the 105 participants in this study, repeated MB-CDI vocabulary scores were analyzed over the course of time spent in early intervention ($M = 25.87$ months, $SD = 9.26$ months). Due to the nested nature of the repeated measures data (i.e. 417 vocabulary assessments nested within 105 students), HLM was selected as the appropriate method of analysis. When multiple assessments are nested within individuals, HLM serves as a statistically appropriate method to analyze changes in longitudinal data (Singer & Willett, 2003). HLM version 8 was used to conduct the analysis.

To investigate the growth of the children across their vocabulary assessments, the nested data were placed into a two-level combined model, where Level 1 represented the vocabulary change over time and Level 2 represented the individual student characteristics that can contribute to vocabulary change over time. In each level, continuous variables were centered at the grand mean of the sample.

The Level 1 repeated measures component of the model was

Level 1 $\quad\quad\quad\quad SCORE_{ti} = \pi_{0i} + \pi_{1i}(TIME) + \varepsilon_{ti},$

where π_{0i} was the average expressive vocabulary score for an individual student (i) at the time (TIME), grand mean centered. TIME represented the age as measured in months at the time of the vocabulary score assessment. Finally, ε_{ti} was the within-individual random error, or the difference between the observed score at time t and the predicted average score of student i. The

error ε_{ti} was assumed to be normally distributed with variance σ_2, capturing the within-individual variation.

The Level 2 component of the model was

Level 2 $\qquad$ $\pi_{0i} = \beta_{00}$

$\qquad\qquad\qquad$ $\pi_{1i} = \beta_{10} + \beta_{11}(\text{HOURS}) + \beta_{12}(\text{AGEID}) + \beta_{13}(\text{ADDLDIAG}) +$

$\qquad\qquad\qquad$ $\beta_{14}(\text{MATERNALED}) + \mu_{1i}$,

where β_{00} was the fixed intercept of the average score at the time of observation age grand mean centered, and β_{10} was the growth rate, or the average monthly change in score for each increase in time variable TIME. The μ_{0i} and μ_{1i} represented the between-individual random effects and were assumed to be normally distributed, capturing between-individual variation. $\beta_{11}(\text{HOURS})$, $\beta_{12}(\text{AGEID})$, $\beta_{13}(\text{ADDLDIAG})$, and $\beta_{14}(\text{MATERNALED})$ were the predictor variables hours of intervention received, age at identification, presence of additional diagnosis, and level of mother's education, all continuous variables centered at the grand mean, respectively. Table 2.4.2 displays the descriptive statistics of each variable included in the model.

Table 2.4.2 Descriptive statistics of the HLM variables

Variable	Description	Mean	St. Dev.	Range
MATERNALED	Mother's highest level of education (years)	16.00	1.98	12 – 20
HOURS	Frequency of early intervention (hours)	396.25	169.2	52 – 831
ADDLDIAG	Additional diagnosis (1 = present, 0 = absent)	n/a	n/a	0 – 1
AGEID	Age at hearing loss identification (months)	6.03	7.79	0.3 - 32

Note. Additional diagnosis was a categorical variable where 1 = present and 0 = absent. This variable was held constant at zero in the analysis.

Best fit of the model was investigated by determining the shape of the data and significant contributors to the data. Analysis revealed a linear relationship to be the best fit of the data, with no quadratic or curvilinear relationship. Additionally, mother's highest level of education did not contribute to the outcome measure. This non-significant factor was removed, and a condensed linear model was constructed. The best fitting model is presented below:

Level 1 $\quad\quad\quad\quad\quad$ $\text{SCORE}_{ti} = \pi_{0i} + \pi_{1i}(\text{TIME}) + \varepsilon_{ti}$

Level 2 $\quad\quad\quad\quad\quad$ $\pi_{0i} = \beta_{00}$

$\quad\quad\quad\quad\quad\quad\quad\quad$ $\pi_{1i} = \beta_{10} + \beta_{11}(\text{HOURS}) + \beta_{12}(\text{AGEID}) + \beta_{13}(\text{ADDLDIAG}) + \mu_{1i}$

Results from the best-fitting modeling are displayed in Table 2.4.3.

Table 2.4.3 Results of hierarchical linear regression model

Fixed effect	Coefficient	Standard error	*t*-ratio (*d.f.*)	*p*-value
Intercept	174.62	6.23	28.02 (311)	<.001
Time slope	18.91	1.63	11.51 (101)	<.001
Hours of intervention	0.02	0.01	2.03 (101)	.045
Additional diagnosis	-6.19	3.11	-1.99 (101)	.050
Age at ID	-0.77	0.19	-3.85 (101)	<.001

The intercept term (174.62) represents the average number of words produced by a child with no additional diagnoses at 27.58 months, when identified at about 6 months old and given 396 hours of intervention over the course of EI (about 4 hours per week). Overall, when each variable was centered at the grand mean, children who are d/hh in this sample demonstrated a growth rate of 18.91 gained words per month over their course of time spent in early intervention. The number of hours of intervention significantly increased the MB-CDI outcome measure, indicating that expressive vocabulary increases by .02 words for every additional hour of intervention received per month. Both additional diagnosis and age at identification also significantly influence expressive vocabulary outcomes. Children who have an additional diagnosis produce 6 fewer words per month, while those with a higher age of hearing loss identification produce 0.77 words fewer per month, as measured by the expressive vocabulary component of the MB-CDI.

The variables of interest indicated a positive effect of hours of intervention on number of words, with a negative effect on vocabulary when an additional diagnosis is present or when a child is identified as d/hh later in life. Because hours of intervention received of the course of EI is a factor that is malleable, meaning that fewer or more hours can implemented, this variable was further analyzed to predict trajectories of expressive vocabulary growth. Predicted growth trajectories were generated by using the best-fitting model.

To represent different growth trajectories by hours of intervention received, three specific values were entered for predictor variable HOURS into the model above, resulting in three separate trajectories for average hours, below average hours, and above average hours received. In each predicted growth model, TIME was set to either 22 months or 32 months, representing the average times at first and last expressive vocabulary assessment. Additionally, ADDLDIAG was held constant at zero and AGEID was held at the grand mean of six months. Thus, expected growth trajectories were generated for a hypothetical child with no additional disabilities diagnosed with hearing loss by six months with three variations in expressive vocabulary growth:

1. When receiving the average number of hours of intervention (396 total hours, averaging 19 hours per month),
2. When receiving 1 SD above the average number of hours of intervention (565 total hours, averaging 25 hours per month),
3. When receiving 1 SD below the average number of hours of intervention (227 total hours, averaging 11 hours per month).

For comparison, the model was also used to generate a typical growth trajectory for children with typical hearing using normative MB-CDI expressive vocabulary growth data (Frank, Braginsky, Yurovsky, & Marchman, 2017). Normative data were only available up to 30 months, thus the two time points used for the typical trajectory were 22 months and 30 months. Figure 2.4.1 demonstrates the growth trajectories of each of the 3 groups of children who are d/hh receiving varied hours of intervention compared to the trajectory of typical expressive vocabulary development.
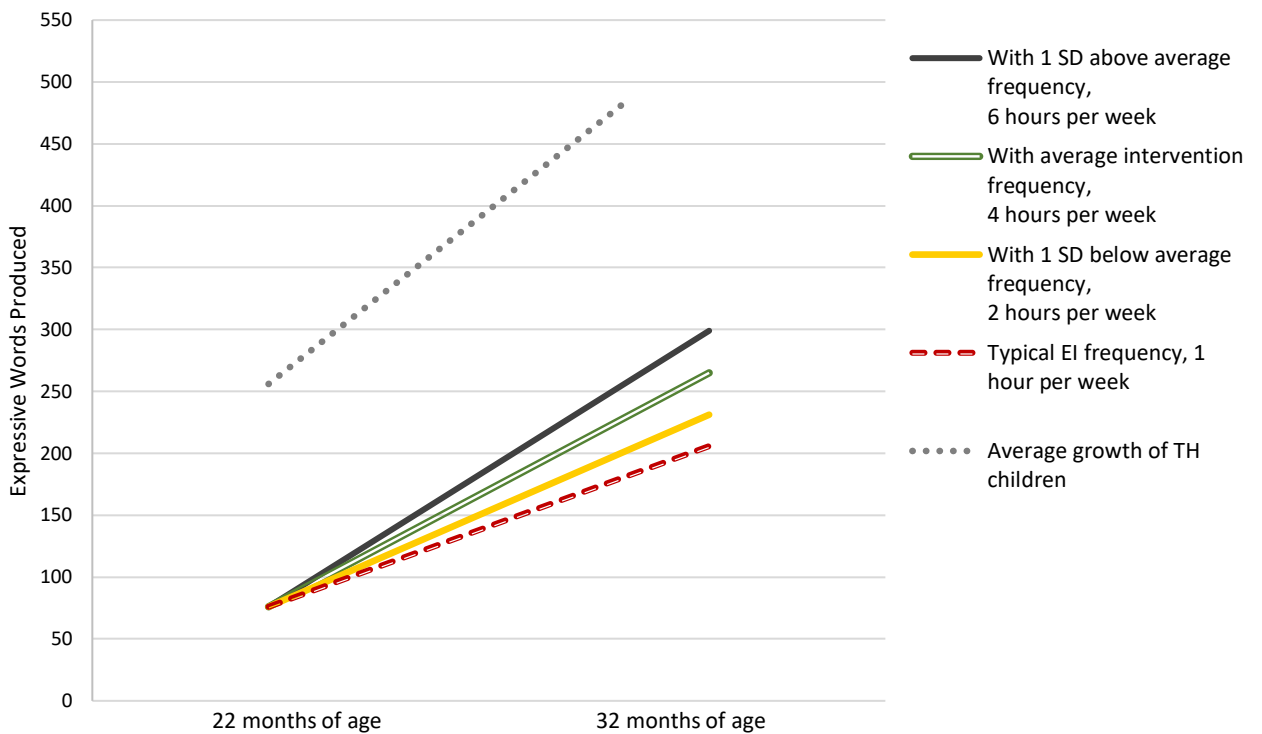

Figure 2.4.1. Expected expressive vocabulary growth by hours of intervention compared to a typical growth trajectory from 22 to 30 months.

Chapter 3: Discussion

This dissertation sought to investigate the rate of early expressive vocabulary development in children who are d/hh aged birth to three years. Although other works have considered the vocabulary achievement over time of children who are d/hh, this study was the first to investigate trajectories of growth in a very young d/hh population using repeated measures of early vocabulary production with a practically-valid measure and a robust statistical analysis. The use of repeated measures vocabulary data allows for a more exact estimate of growth than paired observations of achievement (Yoder & Symons, 2010). Repeated measures were collected using the MB-CDI, a widely-used and clinically effective measure of vocabulary growth which capitalized on parental and teacher knowledge of a child's lexicon. Various studies have found the MB-CDI to be an effective and practical measure for characterizing children's early language skills in both typically-developing and atypically-developing populations (e.g., Dale, Bates, Reznick, & Morisset, 1989; Dale, Dionne, Eley, & Plomin, 2000; Feldman, Dale, Campbell, Colborn, Kurs-Lasky, Rockette, & Paradise, 2005; Yoshinaga-Itano, Snyder, & Day, 1998).

Additionally, this study employed a rigorous statistical analysis to aptly examine growth trajectories within a controlled population of children receiving the same audiologic and educational services. HLM was the most appropriate analysis for this study, as it allowed for precise estimation of expressive vocabulary growth using longitudinal data while simultaneously accounting for variables that may influence the rate of growth (Garson, 2013).

3.1 Research Question 1

How quickly do very young children who are deaf or hard of hearing develop new expressive vocabulary?

The findings of this dissertation indicate that children who are d/hh, under ideal circumstances, can achieve positive expressive vocabulary growth in early years of development when receiving intervention services, including audiologic care and direct therapy for spoken language. More specifically, a growth rate of 19 words per month can be expected for a child who was identified as d/hh with no additional diagnoses by six months of age and who was given a total of 396 hours of educational intervention before the age of 36 months. In other words, it is reasonable for a child given these circumstances to learn vocabulary at a rate of 4 to 5 new words each week.

For reference, it is important to recall that TH children 22 months of age often have expressive lexicons of over 250 words, are producing about 7 new words per week, and are combining two words with meaning (Frank et al., 2017; NIDCD, 2015). The children who are d/hh in this study exhibit expressive vocabulary knowledge of about 76 words at 22 months and are working to build their lexicons at the above-mentioned average rate of 4 to 5 words per week. For a toddler learning to communicate his wants and needs to caregivers, four to five words can carry immense meaning. At this pace, a child can verbally convey when he wants *milk, more*, a *hug*, a *ball*, or to be *all-done*, and engage in beginning conversations with his caregivers as his lexicon continues to grow with each passing week. This fodder for conversation is important because early communication and conversational turn-taking, especially between 18 and 24

months, are predictive of later language and cognitive outcomes (Gilkerson, Richards, Warren, Oller, Russo, & Vohr, 2018).

3.2 Research Question 2

How do hours of instruction received in an early intervention program before age three contribute to differences in early expressive vocabulary growth?

Findings demonstrated that hours of instruction are a statistically significant contributing factor influencing expressive vocabulary growth trajectories for very young children who are d/hh. In other words, an increase in hours of instruction is significantly and positively predictive of greater expressive vocabulary growth. On average, participants received 396 hours, or 4 hours of intervention per week, while enrolled in an early intervention program serving children ages birth to three years. As previously mentioned, the average child who is d/hh with no other neurodevelopmental diagnoses who receives 4 hours of intervention per week is predicted to develop vocabulary at a rate of 19 words per month, or 4.75 words per week. If the dose of hours is increased by just 2 hours, culminating in 6 hours of intervention per week, the growth rate is predicted to increase to almost 6 new words produced per week. With a growth rate of 6 words per week, a child can grow his lexicon by 240 new words over the course of 10 months.

For comparison, consider if a child receives only 1 hour a week of direct intervention service, a service frequency rate which is in line with recommendations from the American Cochlear Implant Association (ACIA) for a newly implanted child (Eskridge, McConkey Robbins, Wilson, & Zombek, 2015). When hours of intervention are decreased to only 1 hour per week, the developmental rate falls to only 3 new words produced each week, or 120 new words produced over a 10-month span. This growth rate is a whopping 50% less than what can

be expected from a child who receives just 5 more hours of instruction per week, with 120 words compared to 240 new words produced over 10 months of intervention. Many professional organizations look to the ACIA recommendation of 1 to 2 hours of service as a guiding source for scheduling therapy sessions (Estabrooks, MacIver-Lux, & Rhoades, 2016; Rhoades & Duncan, 2017). However, substantially more progress can be made during critical periods of development by increasing intervention hours. By providing more intervention services to children who are d/hh under age three, the effect on growth is significant and the gap is lessened between their expressive vocabulary trajectories of development and hearing peers' trajectories.

Overall, the results of the HLM and expected growth trajectory analyses yield important considerations for early intervention policy and programs. The predictive equations revealed that six hours of intervention per week generates expected growth trajectories that are closest to those of their TH peers. Children who are d/hh start out at a distinct vocabulary disadvantage compared to their peers. In this population alone, as detailed in Figure 2.4.1, an initial 180-word gap was documented. TH peers produce an average of 256 words by 22 months compared to the 76 expressive words produced by children who are d/hh. Because of this initial and sizable disadvantage, it is critical for children to achieve steep growth quickly. Educational intervention programs, advocacy groups, and lobbying organizations should be encouraging practitioners and families to provide children with much greater than just one hour of intervention weekly.

3.3 Limitations and Future Directions

The limitations of this study should be considered in the interpretation of the findings. First, the inclusionary criteria and nature of the participants do not allow for conclusions to be drawn about populations which do not share the same characteristics as those in the present

study. A measurement of children who received varied intervention services and who have diverse socioeconomic backgrounds may be more representative of the general population of children who are d/hh learning spoken language. Further, future investigations are needed to determine to better indicate the extent to which differences in intervention services, including audiologic management and educational programs, may contribute to lexical development.

Second, this study included only repeated measures of vocabulary production until age three. Although the expected growth trajectories were positive and linear in nature, forecasting continued steepness of growth, it is unknown how growth trajectories may continue or change after the third year of life. Many children in the population sampled continue to receive educational intervention services after age three, with substantially increased hours of instruction from an average of four hours per week in the birth-to-three program to an average of 40 hours per week after age three in a full-day preschool program. For example, after age three, children may attend an auditory-oral school, such as the one in which the participation sample was drawn, where educational services are offered 8 hours a day, 5 days a week. Each full 8-hour school day consists of specialized instruction implemented by certified teachers of the deaf and speech-language pathologists. Additional research is needed to describe how increased hours of intensive intervention affects vocabulary development in preschool-aged children who are d/hh.

A third limitation of this study is that the developmental periods in which intervention was received between birth and three years of age were not considered in the analysis. The hours of intervention collected for each participant encompassed the total number of hours received beginning from the age of enrollment (as early as birth) to the age of exit (after three years). Within this 36-month time frame, families and children received hours of intervention at varying

intervals. For example, children who enrolled as early as one month of age may have received

between about an hour a week to about an hour a month of intervention, either in the home or in

the program's building. As the child aged, he or she may have received a higher frequency of

hours based on both the caregiver's schedule and the early intervention provider's

recommendations. Then, at 18 months, the option to attend the center-based morning toddler

program became available, where the child would receive an hour of individual instruction plus

two and a half hours of group instruction. An 18-month-old may attend about once a week or so,

and as he or she ages, the frequency of morning center-based visits is likely to increase. It would

not be unusual to find a 30-month old attending the center-based classroom four or five days a

week. With this in mind, it is clear that there is much variability in the number of hours of

intervention a child receives over the course of 36 months. At the same time, the increasing

hours of intervention are corresponding with varying developmental milestones which naturally

occur between birth and three years of age. Little is known about the effect that specific ages in

which intervention was received may have on overall vocabulary outcomes. It would be

interesting to explore the points in which dosage has the largest effect on later lexical

achievement. More work is needed to examine how varying developmental periods may

coincide with hours of intervention and differences in expressive vocabulary growth trajectories.

Fourth on the list of considerations is how the role of caregiver coaching may affect

lexical development. The present study only accounted for the number of direct-to-child hours of

intervention that each participant received from trained early intervention teachers of the deaf. It

is possible that the real-time embedded coaching model adapted at the recruitment site in 2008

(Brooks, 2017) may have incited change in the way that caregivers interacted with their children

outside of the direct-to-child hours of instruction received from the educational environment. Real-time embedded coaching is a method of working with caregivers of children who are d/hh. The method, developed by Betsy Moog Brooks, involves an early intervention provider serving as a coach to a caregiver while the caregiver and child engage in a language-enriching activity together (Brooks, 2017). The coach provides support, including suggestions, feedback, examples, and encouragement to the parent in real-time as she is actively working on an activity with her child. Brooks' 2017 study suggests that coaching may empower both teachers of the deaf providing early intervention services and caregivers working with their children, as well as increase caregiver engagement overall. Further exploration is needed to examine the relationship between real-time embedded coaching and vocabulary growth.

A final limitation is that repeated measures of speech perception scores were not collected to track change in skill level over time. As discussed in the Introduction, speech perception skill development establishes the foundation for identifying phonological information in connected speech streams, parsing apart word boundaries, and building vocabulary knowledge. This study collected only one measure of speech perception skills for each participant: the test score achieved closest to the end of the early intervention program, or age three. The full correlational analysis, as shown in Table 2.4.1, revealed speech perception at the end of early intervention to be significantly correlated with expressive vocabulary at the end of early intervention ($p < 0.01$). This finding is consistent with other studies reporting that speech perception is highly correlated with language outcomes, including vocabulary (e.g., Davidson, Geers, Blamey, Tobey, & Brenner, 2011; deHoog, Langereis, Weerdenburg, Keuning, Knoors, & Verhoeven, 2016; Geers et al. 2011; Geers et al. 2016). Unlike with the outcome variable of

expressive vocabulary, repeated measures of speech perception were not collected for this population. However, it would be interesting to explore the dual trajectories of these measures to determine whether any degree of interdependency exists. Future work is needed to further explore the relationship between early speech perception and expressive vocabulary growth in children who are d/hh ages birth to three.

3.4 Conclusion

In conclusion, this study contributed new information about the rate of expressive vocabulary growth in children who are d/hh aged birth to three years. The study revealed positive developmental trajectories for children learning vocabulary and added to what is known about factors influencing lexical growth. Additionally, this work revealed areas needing further investigation, including how the effects of audiologic management, educational differences, continued intervention services past age three, developmental periods, parental coaching, and speech perception may contribute to expressive vocabulary development. Finally, the findings of this study underscore the need for an increased focus on hours of intervention received prior to age three to cultivate optimal expressive growth trajectories for children who are d/hh.

References

Akhtar, N. (2005). The robustness of learning through overhearing. *Developmental Science*, *8*(2), 199–209. doi: 10.1111/j.1467-7687.2005.00406.x

Akhtar, N., Jipson, J., & Callanan, M. A. (1998). Learning words through eavesdropping. *Infant Behavior and Development*, *21*, 258. doi: 10.1016/s0163-6383(98)91471-0

Akhtar, N., Jipson, J., & Callanan, M. A. (2001). Learning words through overhearing. *Child Development*, *72*(2), 416–430. doi: 10.1111/1467-8624.00287

Apuzzo, M.-R., & Yoshinaga-Itano, C. (1995). Early identification of infants with significant hearing loss and the Minnesota Child Development Inventory. *Seminars in Hearing*, *16*(02), 124–135. doi: 10.1055/s-0028-1083710

Bertenthal, B. I., & Boyer, T. W. (2015). The development of social attention in human infants. *The Many Faces of Social Attention*, 21–65. doi: 10.1007/978-3-319-21368-2_2

Bertoncini, J. (1993). Infants' perception of speech units: Primary representation capacities. In *Developmental neurocognition: Speech and face processing in the first year of life* (pp. 249–257). Boston: Kluwer Academic Publishers.

Bloom, L. (1976). *One word at a time: the use of single word utterances before syntax*. The Hague: Mouton.

Bloom, P. (2000). How children learn the meanings of words. doi: 10.7551/mitpress/3577.001.0001

Boons, T., Brokx, J. P. L., Dhooge, I., Frijns, J. H. M., Peeraer, L., Vermeulen, A., …Wieringen, A. V. (2012). Predictors of spoken language development following pediatric cochlear implantation. *Ear and Hearing*, *33*(5), 617–639. doi: 10.1097/aud.0b013e3182503e47

Brooks, B.M. (2017). Applying andragogical principles to real-time embedded parental coaching when helping their children with hearing loss to talk. (Unpublished doctoral dissertation). Lindenwood University, Saint Charles, Missouri.

Brooks, R., & Meltzoff, A. N. (2008). Infant gaze following and pointing predict accelerated

vocabulary growth through two years of age: a longitudinal, growth curve modeling study. *Journal of Child Language*, *35*(1), 207–220. doi: 10.1017/s030500090700829x

Brown, A. (2012). International phonetic alphabet. The Encyclopedia of Applied Linguistics. doi:10.1002/9781405198431.wbeal0565

Bruce, S. M., & Borders, C. (2015). Communication and language in learners who are deaf and hard of hearing with disabilities: Theories, research, and practice. *American Annals of the Deaf*, *160*(4), 368–384. doi: 10.1353/aad.2015.0035

Carey, S., & Bartlett, E. (1978). Acquiring a single new word. *Papers and Reports on Child Language Development*, *15,* 17-29.

Center for Disease Control and Prevention [CDC] (2019a). Data and statistics about hearing loss in children. *National Center on Birth Defects and Developmental Disabilities.* https://www.cdc.gov/ncbddd/hearingloss/data.html

Center for Disease Control and Prevention [CDC]. (2019b). Summary of 2017 National CDC EHDI Data. *CDC Early Hearing Detection and Intervention (EHDI) Hearing Screening & Follow-up Survey (HSFS).* https://www.cdc.gov/ncbddd/hearingloss/2017-data/documents/01-2017-HSFS-Data-Summary.pdf

Chilosi, A. M., Comparini, A., Scusa, M. F., Berrettini, S., Forli, F., Battini, R., … Cioni, G. (2010). Neurodevelopmental disorders in children with severe to profound sensorineural hearing loss: a clinical study. *Developmental Medicine & Child Neurology*, *52*(9), 856–862. doi: 10.1111/j.1469-8749.2010.03621.x

Ching, T. Y. C. (2015). Is early intervention effective in improving spoken language outcomes of children with congenital hearing loss? *American Journal of Audiology*, *24*(3), 345–348. doi: 10.1044/2015_aja-15-0007

Ching, T. Y. C., Dillon, H., Marnane, V., Hou, S., Day, J., Seeto, M., … Yeh, A. (2013). Outcomes of early- and late-identified children at 3 years of age: findings from a prospective population-based study. *Ear and Hearing*, *34*(5), 535–552. doi: 10.1097/aud.0b013e3182857718

Cuda, D., Murri, A., Guerzoni, L., Fabrizi, E., & Mariani, V. (2014). Pre-school children have better spoken language when early implanted. *International Journal of Pediatric Otorhinolaryngology*, *78*(8), 1327–1331. doi: 10.1016/j.ijporl.2014.05.021

Dale, P. S., Bates, E., Reznick, J. S., & Morisset, C. (1989). The validity of a parent report instrument of child language at twenty months. *Journal of Child Language*, *16*(2), 239–249. doi: 10.1017/s0305000900010394

Dale, P. S., Dionne, G., Eley, T. C., & Plomin, R. (2000). Lexical and grammatical development: a behavioral genetic perspective. *Journal of Child Language*, *27*(3), 619–642. doi: 10.1017/s0305000900004281

Davidson, L. S., Geers, A. E., Blamey, P. J., Tobey, E. A., & Brenner, C. A. (2011). Factors contributing to speech perception scores in long-term pediatric cochlear implant users. *Ear and Hearing*, *32*. doi: 10.1097/aud.0b013e3181ffdb8b

Davidson, L. S., Geers, A. E., & Nicholas, J. G. (2014). The effects of audibility and novel word learning ability on vocabulary level in children with cochlear implants. *Cochlear Implants International*, *15*(4), 211–221. doi: 10.1179/1754762813y.0000000051

Davidson, L. S., Geers, A. E., Uchanski, R. M., & Firszt, J. B. (2019). Effects of early acoustic hearing on speech perception and language for pediatric cochlear implant recipients. *Journal of Speech, Language, and Hearing Research*, *62*(9), 3620–3637. doi: 10.1044/2019_jslhr-h-18-0255

deHoog, B. E., Langereis, M. C., Weerdenburg, M. V., Keuning, J., Knoors, H., & Verhoeven, L. (2016). Auditory and verbal memory predictors of spoken language skills in children with cochlear implants. *Research in Developmental Disabilities*, *57*, 112–124. doi: 10.1016/j.ridd.2016.06.019

Dollaghan, C. A., Campbell, T. F., Paradise, J. L., Feldman, H. M., Janosky, J. E., Pitcairn, D. N., & Kurs-Lasky, M. (1999). Maternal education and measures of early speech and language. *Journal of Speech, Language, and Hearing Research*, *42*(6), 1432–1443. doi: 10.1044/jslhr.4206.1432

Dromi, E. (1987). *Early lexical development*. Cambridge, England: Cambridge University Press.

Duff, F. J., Reen, G., Plunkett, K., & Nation, K. (2015). Do infant vocabulary skills predict school-age language and literacy outcomes? *Journal of Child Psychology and Psychiatry*, *56*(8), 848–856. doi: 10.1111/jcpp.12378

Eilers, R. E., Bull, D. H., Oller, D. K., & Lewis, D. C. (1984). The discrimination of vowel

duration by infants. *The Journal of the Acoustical Society of America*, *75*(4), 1213–1218. doi: 10.1121/1.390773

Eimas, P. D. (1974). Auditory and linguistic processing of cues for place of articulation by infants. *Perception & Psychophysics*, *16*(3), 513–521. doi: 10.3758/bf03198580

Eimas, P. D., Siqueland, E. R., Jusczyk, P., & Vigorito, J. (1971). Speech perception in infants. *Science*, *171*(3968), 303–306. doi: 10.1126/science.171.3968.303

Erber, N. P. (1982). Auditory Training. Washington, DC: Alexander Graham Bell Association for the Deaf.

Eskridge, H.R., McConkey Robbins, A., Wilson, K., & Zombek, L. (2015). Position paper: Pediatric habilitation after cochlear implantation. American Cochlear Implant Alliance. www.acialliance.org/resource/resmgr/docs/aci_paper_pediatric_rehab.pdf

Estabrooks, W., MacIver-Lux, K., & Rhoades, E. A. (2016). *Auditory-verbal therapy for young children with hearing loss and their families and the practitioners who guide them*. San Diego, CA: Plural Publishing.

Feldman, H. M., Dale, P. S., Campbell, T. F., Colborn, D. K., Kurs-Lasky, M., Rockette, H. E., & Paradise, J. L. (2005). Concurrent and predictive validity of parent reports of child language at ages 2 and 3 years. *Child Development*, *76*(4), 856–868. doi: 10.1111/j.1467-8624.2005.00882.x

Fenson, L., Dale, P. S., Reznick, J. S., Bates, E., Thal, D. J., Pethick, S. J., … Stiles, J. (1994). Variability in early communicative development. *Monographs of the Society for Research in Child Development*, *59*(5), i. doi: 10.2307/1166093

Fenson, L., Marchman, V. A., Thal, D. J., Dale, P. S., Reznick, J. S., & Bates, E. (2007). MacArthur-Bates communicative development inventories, Second edition. *PsycTESTS Dataset*. doi: 10.1037/t11538-000

Frank, M. C., Braginsky, M., Yurovsky, D., & Marchman, V. A. (2017). Wordbank: An open repository for developmental vocabulary data. Journal of Child Language, 44(3), 677–694. https://doi.org/10/f96wfq

Gampe, A., Liebal, K., & Tomasello, M. (2012). Eighteen-month-olds learn novel words through overhearing. *First Language*, *32*(3), 385–397. doi: 10.1177/0142723711433584

Ganek, H., Robbins, A. M., & Niparko, J. K. (2012). Language outcomes after cochlear implantation. *Otolaryngologic Clinics of North America*, *45*(1), 173–185. doi: 10.1016/j.otc.2011.08.024

Ganger, J., & Brent, M. R. (2004). Reexamining the vocabulary spurt. *Developmental Psychology*, *40*(4), 621–632. doi: 10.1037/0012-1649.40.4.621

Garson, G. D. (2013). Hierarchical linear modeling: Guide and applications. Thousand Oaks, CA: SAGE Publications, Inc. doi: 10.4135/9781483384450

Geers, A. E. (1994). Techniques for assessing auditory speech perception and lipreading enhancement in young deaf children. *Volta Review*, *96*(5), 85–96.

Geers, A. E., Moog, J. S., Biedenstein, J., Brenner, C., & Hayes, H. (2009). Spoken language Scores of children using cochlear implants compared to hearing age-mates at school entry. *Journal of Deaf Studies and Deaf Education*, *14*(3), 371–385. doi: 10.1093/deafed/enn046

Geers, A. E., Moog, J. S., & Rudge, A. M. (2019). Effects of frequency of early intervention on spoken language and literacy levels of children who are deaf or hard of hearing in preschool and elementary school. *Journal of Early Hearing Detection and Intervention*, *4*(1), 15–27. doi: 10.26077/7pxh-mx41

Geers, A. E., Nicholas, J., Tobey, E., & Davidson, L. (2016). Persistent language delay versus late language emergence in children with early cochlear implantation. *Journal of Speech, Language, and Hearing Research*, *59*(1), 155–170. doi: 10.1044/2015_jslhr-h-14-0173

Geers, A. E., Strube, M. J., Tobey, E. A., Pisoni, D. B., & Moog, J. S. (2011). Epilogue: factors contributing to long-term outcomes of cochlear implantation in early childhood. *Ear and Hearing*, *32*. doi: 10.1097/aud.0b013e3181ffd5b5

Gershkoff-Stowe, L., & Hahn, E. R. (2007). Fast mapping skills in the developing lexicon. *Journal of Speech, Language, and Hearing Research*, *50*(3), 682–697. doi: 10.1044/1092-4388(2007/048)

Gilkerson, J., Richards, J. A., Warren, S. F., Oller, D. K., Russo, R., & Vohr, B. (2018). Language experience in the second year of life and language outcomes in late childhood. *Pediatrics*, *142*(4). doi: 10.1542/peds.2017-4276

Gordon, K. A., Wong, D. D. E., Valero, J., Jewell, S. F., Yoo, P., & Papsin, B. C. (2011). Use it or Lose it? Lessons learned from the developing brains of children who are deaf and use cochlear implants to hear. *Brain Topography*, *24*(3-4), 204–219. doi: 10.1007/s10548-011-0181-2

Graven, S. N., & Browne, J. V. (2008). Sensory development in the fetus, neonate, and infant: Introduction and overview. *Newborn and Infant Nursing Reviews*, *8*(4), 169–172. doi: 10.1053/j.nainr.2008.10.007

Guardino, C., & Cannon, J. E. (2015). Theory, research and practice for students who are deaf and hard of hearing with disabilities: Addressing the challenges from birth to postsecondary education. *American Annals of the Deaf*, *160*(4), 347–355. doi: 10.1353/aad.2015.0033

Harris, M. S., Kronenberger, W. G., Gao, S., Hoen, H. M., Miyamoto, R. T., & Pisoni, D. B. (2013). Verbal short-term memory development and spoken language outcomes in deaf children with cochlear implants. *Ear and Hearing*, *34*(2), 179–192. doi: 10.1097/aud.0b013e318269ce50

Hart, B., & Risley, T. R. (1995). Meaningful differences in the everyday experience of young American children. Paul H Brookes Publishing.

Hayes, H., Geers, A. E., Treiman, R., & Moog, J. S. (2009). Receptive vocabulary development in deaf children with cochlear implants: Achievement in an intensive auditory-oral educational setting. *Ear and Hearing*, *30*(1), 128–135. doi: 10.1097/aud.0b013e3181926524

Heibeck, T., & Markman, E. (1985). *Word learning in children: An examination of fast mapping*. Washington D.C.: National Science Foundation.

Hoff, E. (2003). The specificity of environmental influence: socioeconomic status affects early vocabulary development via maternal speech. *Child Development*, *74*(5), 1368–1378. doi: 10.1111/1467-8624.00612

Hoff, E. (2006). How social contexts support and shape language development. *Developmental Review*, *26*(1), 55–88. doi: 10.1016/j.dr.2005.11.002

Houston, D. M., Stewart, J., Moberly, A., Hollich, G., & Miyamoto, R. T. (2012). Word learning

in deaf children with cochlear implants: effects of early auditory experience. *Developmental Science*, *15*(3), 448–461. doi: 10.1111/j.1467-7687.2012.01140.x

Huttenlocher, J., Vasilyeva, M., Waterfall, H. R., Vevea, J. L., & Hedges, L. V. (2007). The varieties of speech to young children. *Developmental Psychology*, *43*(5), 1062–1083. doi: 10.1037/0012-1649.43.5.1062

Huttenlocher, J., Waterfall, H., Vasilyeva, M., Vevea, J., & Hedges, L. V. (2010). Sources of variability in children's language growth. *Cognitive Psychology*, *61*(4), 343–365. doi: 10.1016/j.cogpsych.2010.08.002

IBM Corp. (2016). IBM SPSS Statistics for Windows, Version 24.0. Armonk, NY: IBM Corp.

Johnson, S. C., Ok, S.-J., & Luo, Y. (2007). The attribution of attention: 9-month-olds? interpretation of gaze as goal-directed action. *Developmental Science*, *10*(5), 530–537. doi: 10.1111/j.1467-7687.2007.00606.x

Joint Committee on Infant Hearing [JCIH]. (2007) Year 2007 position statement: Principles and guidelines for early hearing detection and intervention programs. *Pediatrics*, *120*(4), 898–921. doi: 10.1542/peds.2007-2333

Joint Committee on Infant Hearing [JCIH]. (2019) Year 2019 position statement: Principles and guidelines for early hearing detection and intervention programs. *Journal of Early Hearing Detection and Intervention*, *4*(2), 1–44. doi: 10.15142/fptk-b748

Kay-Raining Bird, E., & Chapman, R. (1998). Partial representation and phonological selectivity in the comprehension of 13- to 16-months-old. *First Language, 18*, 105-127. doi:10.1177/014272379801805204.

Kirk, K. I., Pisoni, D. B., & Osberger, M. J. (1995). Lexical effects on spoken word recognition by pediatric cochlear implant users. *Ear and Hearing*, *16*(5), 470–481. doi: 10.1097/00003446-199510000-00004

Leadsom, A., Field, F., Burstow, P. and Lucas, C. (2013) 1001 critical days: the importance of the conception to age two period, Retrieved from https://www.nwcscnsenate.nhs.uk/files/8614/7325/1138/1001cdmanifesto.pdf

Ling, D. (1976). *Speech and the hearing-impaired child: Theory and practice.* Washington, DC:

Alexander Graham Bell Association for the Deaf.

Ling, D. (1989). *Foundations of spoken language for the hearing-impaired child.* Washington, DC: Alexander Graham Bell Association for the Deaf.

Lore, D., Ladner, P., & Suskind, D. (2018). Talk, read, sing: Early language exposure as an overlooked social determinant of health. *Pediatrics*, *142*(3). doi: 10.1542/peds.2018-2007

Marchman, V. A., & Fernald, A. (2008). Speed of word recognition and vocabulary knowledge in infancy predict cognitive and language outcomes in later childhood. *Developmental Science*, *0*(0). doi: 10.1111/j.1467-7687.2007.00671.x

McCarthy, D. (1954). Language development in children. In *Manual of Child Development* (2nd ed., pp. 492–630). New York: Wiley.

McLaughlin, S. (1998). *Introduction to language development*. San Diego: Singular Publishing Group, Inc.

Meinzen-Derr, J., Sheldon, R., Grether, S., Altaye, M., Smith, L., Choo, D. I., & Wiley, S. (2018). Language underperformance in young children who are deaf or hard-of-hearing: Are the expectations too low? *Journal of Developmental & Behavioral Pediatrics*, *39*(2), 116–125. doi: 10.1097/dbp.0000000000000509

Mitchell, R. E., & Karchmer, M. A. (2004). Chasing the mythical ten percent: Parental hearing status of deaf and hard of hearing students in the united states. *Sign Language Studies*, *4*(2), 138–163. doi: 10.1353/sls.2004.0005

Moeller, M. P. (2000). Early intervention and language development in children who are deaf and hard of hearing. *Pediatrics*, *106*(3). doi: 10.1542/peds.106.3.e43

Moog, J. S., & Geers, A. E. (1990). Early speech perception test for profoundly deaf children. St. Louis: Central Institute for the Deaf.

Moog, J. S., & Geers, A. E. (2012). Early speech perception test. St. Louis: Central Institute for the Deaf.

Moon, C. K., Lagercrantz, H. K., & Kuhl, P. K. (2013). Language experienced in utero affects vowel perception after birth: a two-country study. *Acta Paediatrica*, *102*(2), 156–160. doi: 10.1111/apa.12098

National Institute on Deafness and other Communication Disorders [NIDCD]. (2015). NIDCD Fact Sheet Hearing and Balance: Your baby's hearing and communicative development checklist. *National Institutes of Health.* https://www.nidcd.nih.gov/sites/default/files/Documents/health/hearing/NIDCD-Hearing-Development-Checklist.pdf

National Institute on Deafness and other Communication Disorders [NIDCD]. (2017). New law to strengthen early hearing screening program for infants and children. *National Institutes of Health.* https://www.nidcd.nih.gov/news/2017/new-law-early-hearing-screening-infants-and-children

Nelson, K. (1973). Structure and strategy in learning to talk. *Monographs of the Society for Research in Child Development*, *38*(1/2), 1. doi: 10.2307/1165788

Nicholas, J. G., & Geers, A. E. (2007). Will they catch up? The role of age at cochlear implantation in the spoken language development of children with severe to profound hearing loss. *Journal of Speech, Language, and Hearing Research*, *50*(4), 1048–1062. doi: 10.1044/1092-4388(2007/073)

Nicholas, J. G., & Geers, A. E. (2013). Spoken language benefits of extending cochlear implant candidacy below 12 months of age. *Otology & Neurotology*, *34*(3), 532–538. doi: 10.1097/mao.0b013e318281e215

Nott, P., Cowan, R., Brown, P. M., & Wigglesworth, G. (2009). Early language development in children with profound hearing loss fitted with a device at a young age: Part I—the time period taken to acquire first words and first word combinations. *Ear and Hearing*, *30*(5), 526–540. doi: 10.1097/aud.0b013e3181a9ea14

Office of Research Support and International Affairs. (2014). Regional and national summary report of data from the 2013–2014 annual survey of deaf and hard of hearing children and youth; *Office of Research Support and International Affairs*: Washington, DC.

Pisoni, D. B., Kronenberger, W. G., Roman, A. S., & Geers, A. E. (2011). Measures of digit span and verbal rehearsal speed in deaf children after more than 10 years of cochlear implantation. *Ear and Hearing*, *32*. doi: 10.1097/aud.0b013e3181ffd58e

Raudenbush, S.W., Bryk, A.S, Cheong, Y.F. & Congdon, R. (2019). HLM 8 for Windows [Computer software]. Skokie, IL: Scientific Software International, Inc.

Reznick, J. S., & Goldfield, B. A. (1992). Rapid change in lexical development in comprehension and production. *Developmental Psychology*, *28*(3), 406–413. doi: 10.1037/0012-1649.28.3.406

Rhoades, E. A., & Duncan, J. (2017). *Auditory-verbal practice: family-centered early intervention*. Springfield, IL: Charles C Thomas, Publisher, Ltd.

Ross, M., & Lerman, J. (1970). A picture identification test for hearing-impaired children. *Journal of Speech and Hearing Research*, *13*(1), 44–53. doi: 10.1044/jshr.1301.44

Rowe, M. L. (2012). A longitudinal investigation of the role of quantity and quality of child-directed speech in vocabulary development. *Child Development*, *83*(5), 1762–1774. doi: 10.1111/j.1467-8624.2012.01805.x

Saffran, J. R., Aslin, R. N., & Newport, E. L. (1996). Statistical learning by 8-month-old infants. *Science*, *274*(5294), 1926–1928. doi: 10.1126/science.274.5294.1926

Saffran, J. R. (2003). Statistical language learning. *Current Directions in Psychological Science*, *12*(4), 110–114. doi: 10.1111/1467-8721.01243

Sharma, A., Campbell, J., & Cardon, G. (2015). Developmental and cross-modal plasticity in deafness: Evidence from the P1 and N1 event related potentials in cochlear implanted children. International Journal of Psychophysiology, 95(2), 135–144.

Sharma, A., Dorman, M. F., & Spahr, A. J. (2002). Rapid development of cortical auditory evoked potentials after early cochlear implantation. Neuroreport, 13(10), 1365–1368.

Sharma, A., Gilley, P. M., Dorman, M. F., & Baldwin, R. (2007). Deprivation-induced cortical reorganization in children with cochlear implants. International Journal of Audiology, 46(9), 494–499

Sharma, A., Nash, A. A., & Dorman, M. (2009). Cortical development, plasticity and re-organization in children with cochlear implants. *Journal of Communication Disorders*, *42*(4), 272–279. doi: 10.1016/j.jcomdis.2009.03.003

Shonkoff, J. (2017). Brain Architecture. *Center on the Developing Child: Harvard University*.

Retrieved from https://developingchild.harvard.edu/science/key-concepts/brain-architecture/

Singer, J. D., & Willett, J. B. (2003). *Applied longitudinal data analysis: modeling change and event occurrence*. Oxford: Oxford University Press.

Song, L., Spier, E. T., & Tamis-Lemonda, C. S. (2013). Reciprocal influences between maternal language and childrens language and cognitive development in low-income families. *Journal of Child Language*, *41*(2), 305–326. doi: 10.1017/s0305000912000700

Suggate, S., Schaughency, E., Mcanally, H., & Reese, E. (2018). From infancy to adolescence: The longitudinal links between vocabulary, early literacy skills, oral narrative, and reading comprehension. *Cognitive Development*, *47*, 82–95. doi: 10.1016/j.cogdev.2018.04.005

Szagun, G., & Stumper, B. (2012). Age or experience? The influence of age at implantation and social and linguistic environment on language development in children with cochlear implants. *Journal of Speech, Language, and Hearing Research*, *55*(6), 1640–1654. doi: 10.1044/1092-4388(2012/11-0119)

Thal, D., Desjardin, J. L., & Eisenberg, L. S. (2007). Validity of the Macarthur–Bates communicative development inventories for measuring language abilities in children with cochlear implants. *American Journal of Speech-Language Pathology*, *16*(1), 54–64. doi: 10.1044/1058-0360(2007/007)

Tomasello, M. (1995). Joint attention as social cognition. In *Joint Attention: Its Origins and Role in Development* (pp. 103–130). Hillsdale, NJ.

Tomasello, M., & Todd, J. (1983). Joint attention and lexical acquisition style. *First Language*, *4*(12), 197-211. doi:10.1177/014272378300401202

Tomblin, J. B., Oleson, J. J., Ambrose, S. E., Walker, E., & Moeller, M. P. (2014). The influence of hearing aids on the speech and language development of children with hearing loss. *JAMA Otolaryngology–Head & Neck Surgery*, *140*(5), 403. doi: 10.1001/jamaoto.2014.267

Tsao, F.-M., Liu, H.-M., & Kuhl, P. K. (2004). Speech perception in infancy predicts language development in the second year of life: A longitudinal study. *Child Development*, *75*(4), 1067–1084. doi: 10.1111/j.1467-8624.2004.00726.x

Vohr, B., Jodoin-Krauzyk, J., Tucker, R., Johnson, M. J., Topol, D., & Ahlgren, M. (2008). Early language outcomes of early-identified infants with permanent hearing loss at 12 to 16 months of age. *Pediatrics*, *122*(3), 535–544. doi: 10.1542/peds.2007-2028

Vohr, B., Jodoin-Krauzyk, J., Tucker, R., Topol, D., Johnson, M. J., Ahlgren, M., & Pierre, L. (2011). Expressive vocabulary of children with hearing loss in the first 2 years of life: impact of early intervention. *Journal of Perinatology*, *31*(4), 274–280. doi: 10.1038/jp.2010.110

Walker, D., Greenwood, C., Hart, B., & Carta, J. (1994). Prediction of School Outcomes Based on Early Language Production and Socioeconomic Factors. *Child Development*, *65*(2), 606. doi: 10.2307/113140

Walker, E. A., Redfern, A., & Oleson, J. J. (2019). Linear mixed-model analysis to examine longitudinal trajectories in vocabulary depth and breadth in children who are hard of hearing. *Journal of Speech, Language, and Hearing Research*, *62*(3), 525–542. doi: 10.1044/2018_jslhr-l-astm-18-025

Willett, J. B., Singer, J. D., & Martin, N. C. (1998). The design and analysis of longitudinal studies of development and psychopathology in context: Statistical methods and methodological recommendations. Development and Psychopathology, 10, 395–426.

Woodward, A.L. (2003). Infants' developing understanding of the link between looker and object. Developmental Science, 6 (3), 297–311.

Woodward, A., Markman, E., & Fitzsimmons, C. (1994). Rapid word learning in 13- and 18-month-olds. *Developmental Psychology, 30*, 553-566. doi: 10.1037/0012 1649.30.4.

Yoder, P., & Symons, F. (2010). *Observational measurement of behavior.* New York: Springer.

Yoshinaga-Itano, C., Sedey, A. L., Coulter, D. K., & Mehl, A. L. (1998). Language of early- and later-identified children with hearing loss. *Pediatrics*, *102*(5), 1161–1171. doi: 10.1542/peds.102.5.116.

Yoshinaga-Itano, C., Sedey, A. L., Wiggin, M., & Chung, W. (2017). Early hearing detection and vocabulary of children with hearing loss. *Pediatrics*, *140*(2). doi: 10.1542/peds.2016-2964

Yoshinaga-Itano, C., Snyder, L. S., & Day, D. (1998). The relationship of language and symbolic play in children with hearing loss. *Volta Review*, *100*, 135–164.