

**PREDICTORS OF READING COMPREHENSION OUTCOMES IN
SCHOOL-AGED CHILDREN WITH COCHLEAR IMPLANTS**

by

Anita Fay Vereb

A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
(Educational Studies)
in The University of Michigan
2012

Doctoral Committee:

Professor C. Addison Stone, Co-Chair
Professor Teresa A. Zwolan, Co-Chair
Professor Joanne F. Carlisle
Associate Professor Kai S. Cortina

© Anita F. Vereb

2012

DEDICATION

In loving memory of David C. Vereb, David J. Johnson and Layne M. Anderson

“What lies behind us and what lies before us are tiny matters compared to what lies within us.”

~ Ralph Waldo Emerson

ACKNOWLEDGEMENTS

First and foremost, I would like to express my appreciation to the families who participated in this study. I am forever grateful for their support and commend their dedication to advancing research in the area of pediatric cochlear implantation. I would also like to thank those who helped in the recruitment phase of this study. Additionally, I would like to recognize the Rackham Graduate School, the School of Education, and the Institute for Human Adjustment at the University of Michigan for their financial support.

Next, I would like to acknowledge my committee members who have given countless hours of their time, selflessly, to mentor me over these past five years; words can only begin to express my gratitude. To Addison, my academic advisor and co-chair, I admire your calming presence, integrity, intelligence, and generosity. Thank you for your insight and careful attention to detail on countless drafts of this dissertation. Thanks too, for always being there to help celebrate in various milestones with a little extra lime. To Terry, my supervisor and co-chair, I still remember that performance evaluation when you suggested I consider a Ph.D.; thanks for believing in me then, and now. I truly appreciate your support and guidance, which has been instrumental in my professional growth as a clinician and researcher. I look forward to collaborating with you in the years to come. To Joanne, my research advisor and committee member, being a part of your research team over the past five years has been invaluable. You inspire me with your ambition, determination, integrity, and ability to see the potential in everyone. You

have been so gracious with your time, even if it meant getting together on weekends, evenings, or squeezing me in over lunch. I hope that I can be half the mentor to others, as you have been to me. To Kai, my stats confidant and committee member, I cherish our time spent together, bonding over the creation and analyses of numerous datasets. You have taught me that: 1) syntax “rules”, 2) chocolate is an important variable to consider in any equation, and 3) there is always a silver lining, not only in what the data reveal, but in life, in general. You exude optimism, which I will take with me as I begin the next chapter of my professional career.

Additionally, I would like to acknowledge my fellow colleagues at the University of Michigan Otolaryngology Department and fellow research team members at the School of Education and Institute of Social Research for their comradeship and words of encouragement over the years. I would also like to extend my appreciation to Joan McCoy, Office of Student Affairs, for keeping me on track, ensuring that I met the yearly Ph.D. requirements, and for being my silent cheerleader.

Lastly, I offer my gratitude to my family and friends who have been my rock throughout this entire process. To Cathy, Christine, and Emily, just keep swimming, just keep swimming! Nemo is our hero! To Kerri, good friends and NYPD always go together. To Ashley, thank you for your support, both personally and professionally. To the PA gang and the IC, thank you for accepting me unconditionally, despite my split “BA” personality over these past five years. To my parents, I am blessed to be part of such a loving family– thank you for always being there for me, encouraging me, and supporting me in all of my endeavors.

As I reflect on the Ph.D. experience, it truly has been about the journey and not the destination (i.e., the process and not the final product). Thank you to all who played an integral role in this journey. It sure has been a memorable adventure.

TABLE OF CONTENTS

DEDICATION	ii
ACKNOWLEDGEMENTS	iii
LIST OF TABLES	x
LIST OF FIGURES	xi
ABSTRACT	xii
CHAPTER 1 Introduction.....	1
CHAPTER 2 Literature Review	6
Brief Background on Cochlear Implants	6
Theoretical Frameworks	9
Critical Period Hypothesis	10
Qualitative-Similarity Hypothesis.	12
Transactional Model of Development.	13
Integrating the frameworks.	14
Factors Influencing the Effectiveness of Cochlear Implants	16
Child factors.....	17
Anatomy of the inner ear	17
Onset of deafness and amount of residual hearing pre-implant.....	18

Cognitive functioning.	19
Age of identification of hearing loss and age at implant activation.	22
Contextual factors.	24
Educational or communication approach.....	24
Family factors.	26
Language and Reading Development	29
Speech perception and speech production.	32
Phonological awareness and phonological processing.	35
Word recognition.	39
Language comprehension and vocabulary.....	41
Reading comprehension.....	46
Summary and Next Steps: Language and Reading Development	51
CHAPTER 3 Methods	55
Sample and Participant Selection.....	55
Study Measures.....	61
Cognitive functioning.	61
Speech perception.	63
Phonological awareness and word recognition.....	65
Oral language.....	66
Reading comprehension.....	68
Speech processor function and mapping.....	70

Parental questionnaire: Home support for literacy development.....	70
Data Collection	71
Statistical Analyses	73
CHAPTER 4 Results.....	78
Word Reading and Language Comprehension	78
Reading Comprehension Outcomes in Children with CIs	81
Examining the Effects of Auditory, Word Reading, and Linguistic Abilities on Reading Comprehension.....	82
Examining Indirect Effects on Reading Comprehension Outcomes	85
Examining Combined Effects (Indirect and Direct) on Reading Comprehension Outcomes	88
Structural Equation Modeling of Predictors of Reading Comprehension	95
Summary of Findings.....	100
CHAPTER 5 Discussion.....	102
Reading Comprehension Outcomes.....	103
Potential Predictors of Reading Comprehension	107
Age at implant activation.....	108
Amount of residual hearing preoperatively.	110
Parental education level and home support for literacy development.	112
Word recognition.	115
Language and vocabulary development.....	116
Limitations	119

Measures	119
Sample.....	121
Future Studies	122
Conclusion	125
APPENDIX A.....	127
Parental Questionnaire	127
BIBLIOGRAPHY.....	139

LIST OF TABLES

Table 1. <i>Demographics and Hearing History of Participants</i>	58
Table 2. <i>Measures of Performance</i>	69
Table 3. <i>Children’s Performance on Speech Perception, Language, and Reading Measures</i>	80
Table 4. <i>Correlations of Measures</i>	83
Table 5. <i>Auditory, Word Reading, and Language Measures as Predictors of Children’s Reading Comprehension</i>	85
Table 6. <i>Correlations of Age at Implantation, Child, and Environmental Factors with Auditory, Word Reading, and Language Measures</i>	86
Table 7. <i>Age at Implant Activation and Residual Hearing as Predictors of Children’s Reading Comprehension</i>	90
Table 8. <i>Predictors with Direct Effects on Children’s Reading Comprehension Outcomes</i>	93
Table 9. <i>SEM Standardized Model Results</i>	97
Table 10. <i>Summary of SEM Goodness of Fit</i>	97
Table 11. <i>SEM Correlations of Age at Implant Activation and Parental Education with Vocabulary and Reading Measures</i>	99
Table 12. <i>SEM Fitted Residuals</i>	100

LIST OF FIGURES

Figure 1. <i>Standardized Beta Coefficients of Multiple Regression Models of Age at Implant Activation, Child, and Environmental Factors as Predictors of Children’s Auditory, Word Reading, and Linguistic Abilities</i>	88
Figure 2. <i>Significant Standardized Coefficients of the Final Path Analysis</i>	94
Figure 3. <i>Final SEM Model: Path Diagram for Testing the Effects of Age at Implant Activation, Parent Education, Word Recognition, and Vocabulary on Children’s Reading Comprehension</i>	96

ABSTRACT

By bypassing damaged portions of the inner ear and stimulating the auditory nerve directly, cochlear implants (CIs) provide children with significant hearing loss with greater access to the sound representations of words essential for speech and language development and later literacy learning. To date, research on the educational benefits of CIs has primarily focused on children's speech and language development and less on the potential improvements in literacy achievement stemming from this medical advance. The purpose of this study was to examine whether the initial speech and language benefits for young children with CIs are associated with improved reading comprehension in the early elementary years, and if so, what factors appear to be significant predictors of improved reading outcomes.

Thirty-one children with CIs (ages 7 - 11 years), with an average age at implant activation of 1.9 years, participated in this study. Over two-thirds (68%) of the children scored within or above the average range for their age (i.e., standard score ≥ 85) on the Passage Comprehension subtest of the Woodcock-Johnson III-NU Tests of Achievement. However, the group mean remained more than half a standard deviation (SD) below the norm population, despite an above-average group mean on measures of Performance IQ. Path analyses revealed that proficiency in children's reading comprehension outcomes was associated with a younger age at implant activation, higher parental education, greater word recognition proficiency, and a broader vocabulary base.

These findings highlight the importance of early identification and treatment of hearing loss. Additionally, they indicate the need for continued research and interventions targeted at supporting children's vocabulary learning in the home and school context to foster reading development in children with CIs.

CHAPTER 1

Introduction

Early reading success is a key prerequisite for children's learning in later years (Neuman & Dickinson, 2001; Snow, Burns, & Griffin, 1998). A longitudinal study conducted by Juel (1988) revealed that a high proportion (88%) of children identified with poor reading abilities at the end of first grade remained poor readers at the end of fourth grade. Scarborough (2001) reported that 65-75% of children designated as reading disabled in the primary grades continued to have reading difficulties throughout their school years. Children experiencing reading difficulties at an early age struggle with learning new material and are likely to demonstrate reading difficulties throughout their schooling and beyond.

In recent years, improving the literacy competency of our children has received increased national attention in both the educational and public policy arenas. Yet, despite increased awareness and federal initiatives (e.g., Reading First), children's outcomes in reading remain relatively unchanged (Gamse, Jacob, Horst, Boulay, & Unlu, 2008; National Center for Education Statistics [NCES], 2011). Results from the 2011 National Assessment of Educational Progress (NAEP) in reading revealed that only 34% of fourth-graders were reading at or above a proficient level, and only 8% were reading at an advanced level. These percentages remained unchanged when compared to the 2007 and 2009 NAEP fourth-grade reading results.

Among the children at risk for underachievement in reading are those identified with sensory and cognitive impairments. Children with hearing loss represent one subgroup with particular challenges in language and literacy development. Research continues to show that approximately 50 percent of 18-year old students who are deaf and hard-of-hearing read at a 4th grade reading level or below (Gallaudet Research Institute, 2005; Traxler, 2000). Interested in how to support literacy development in children with hearing loss, Schirmer and McGough (2005) reviewed the research on early literacy in children with hearing loss and found some similarities between the reading processes in children who are deaf and hard of hearing and their peers with typical hearing. However, overall, research in this area was limited. So whether the conclusions of early literacy development for typically developing children drawn by prominent panels of experts such as the National Reading Panel ([NRP], NICHD, 2000) apply to children with hearing loss remains debatable without further empirical evidence.

Of the many research needs related to language and literacy acquisition in children with hearing loss, one area that warrants immediate attention is language and literacy development in children with cochlear implants (CIs). Cochlear implants hold much promise for improved language and literacy development in children with severe to profound hearing loss. By bypassing damaged portions of the ear, CIs allow for direct stimulation of the auditory nerve, providing children with significant hearing loss with better access to the auditory signals associated with speech and language development, and later literacy learning. Additionally, as a result of a greater awareness of CIs as a standard treatment of care (Archbold et al., 2008) and early identification of hearing loss through Early Hearing Detection and Intervention (EHDI) programs (Spencer &

Marschark, 2003), an increasing number of young children (i.e., children under the age of 2 years) are undergoing cochlear implantation during the critical period of auditory/oral development. Minimal research exists on this new, younger generation of pediatric cochlear implant recipients. Thus, research in the field of language and literacy among pediatric CI users is critical if we are to understand the academic needs of this ever-growing population of children who are deaf and hard-of-hearing.

Advances in CI technology have dramatically altered the educational and communication opportunities available to children with profound deafness. Empirical studies have demonstrated improvements in children's language outcomes after cochlear implantation, with many children reaching language outcomes commensurate with their typical hearing peers (Geers, Nicholas, & Sedey, 2003; Svirsky, Robbins, Kirk, Pisoni & Miyamoto, 2000). However, findings demonstrate significant variability in individual performance post-implant, and for some, language delays still remain (Connor & Zwolan, 2004; Geers, Tobey, Moog, & Brenner, 2008). There are many factors that can influence outcomes following cochlear implantation, such as anatomy of the inner ear, age at implantation, amount of residual hearing pre-implant, duration of device use, and device programming (e.g., Geers, 2003; Geers et al., 2008; Niparko et al., 2010; Zeng 2004). Empirical evidence has demonstrated that children with cochlear implants may have the potential to obtain speech and language skills comparable to those of their typically hearing peers; however, limited research exists on whether these age-appropriate findings extend to children's reading comprehension following cochlear implantation.

In short, for all the research now available on the benefits of cochlear implantation, there still remains a tremendous need to understand the effects of CIs on

language and reading development in the school years, as well as factors associated with this development. As the number of children receiving cochlear implants during their first few years of life continues to rise, research in this field of study is imperative to ensure that children are able to maximize the benefits received from cochlear implantation.

The purpose of this study was to examine whether factors identified in the literature to influence speech and language development in children with typical hearing and children with CIs are also predictive of children's reading comprehension outcomes after cochlear implantation. The use of path analyses and structural equation modeling (SEM) allowed for the examination of direct and indirect effects of multiple factors known to mediate reading comprehension among normal hearing children in order to understand the complex interactions of language and literacy learning in children with cochlear implants. The current study contributes to a deeper understanding of the development of reading comprehension and factors that influence this development in school-aged children with cochlear implants than what has been previously reported in the literature. This deeper understanding can lead to changes in instructional practices for children who are deaf and hard of hearing, further supporting their language and literacy development after cochlear implantation. The following research questions were posed in this study:

RQ1: *What proportion of children with cochlear implants score within the average range for reading comprehension compared with normative data for children with typical hearing?*

RQ2: *Which aspects of children's present auditory, word reading, and linguistic abilities are associated with variation in reading comprehension?*

RQ3: *How do age at implant activation, child, and environment-related factors contribute to individual differences in children's present auditory, word reading, and linguistic abilities?*

RQ4: *How do age at implant activation, child, and environment-related factors contribute (directly or indirectly) to individual differences in reading comprehension in children with cochlear implants when controlling for present auditory, word reading, and linguistic abilities?*

The next chapter (Chapter 2) provides the rationale for the present study, based on a review of the research available to date on speech, language, and literacy outcomes in children with CIs. Chapter 3 provides an overview of the study methodology, including study recruitment and participants, data sources and collection, and statistical methods used to analyze the data. Chapter 4 focuses on the results of data analyses as they relate to the aforementioned guiding research questions. Chapter 5 summarizes the findings, and how they support or extend the current literature on language and literacy acquisition in children with CIs, and concludes with a discussion of study limitations and suggested directions for future research.

CHAPTER 2

Literature Review

In this chapter, I first provide a brief background on cochlear implantation and address the underlying theoretical frameworks associated with research in this area. I then provide a review of the research available to date on the various factors associated with speech, language, and literacy outcomes in children with CIs. Next, I summarize what present research has revealed as it relates to cochlear implantation as a means to foster children's speech, language, and literacy development. Finally, based on the review of the literature, I discuss the hypotheses of the present study, which was designed to investigate further the effect of cochlear implantation on children's reading comprehension outcomes in the early elementary years.

Brief Background on Cochlear Implants

The field of cochlear implants (CIs) is still relatively young. The Food and Drug Administration (FDA) approved the use of CIs in adults in 1984, and the initial pediatric clinical trials (ages 5 years and older) began in 1985. According to the FDA, as of December 2010, approximately 219,000 people worldwide have received implants. In the United States, roughly 42,600 adults and 28,400 children have undergone cochlear implantation (<http://www.nidcd.nih.gov/health/hearing/coch.asp>). Over time, the criterion for pediatric cochlear implantation was lowered from 5 years of age in 1985, to 2 years of age, to 18 months of age, and eventually to 12 months of age in 2000. Current

FDA guidelines stipulate that children must be at least 12 months of age, present with a bilateral severe-to-profound sensorineural hearing loss (SNHL), and receive limited benefit from amplification (i.e., hearing aids) in order to meet pediatric cochlear implant candidacy.¹

Outcomes following cochlear implantation have improved greatly over the past quarter of a century. During its inception, the CI was a single-electrode device designed to enhance lip-reading and provide sound awareness for adults with profound deafness. Today, the CI is an intricate multi-electrode device with the potential to support children as young as 12 months of age in reaching speech and language outcomes comparable to those of their typically hearing peers. CIs are now recognized as standard treatment for individuals with severe-to-profound SNHL hearing loss. Most insurance companies cover the cost of cochlear implantation, including Medicare, Medicaid, the Veteran's Administration, and other public and commercial health care plans (<http://www.fda.gov/MedicalDevices/ProductsandMedicalProcedures/ImplantsandProsthetics/CochlearImplants/ucm062866.htm>). Until recently, cochlear implantation occurred unilaterally; however, an increasing number of insurance companies now cover bilateral cochlear implantation. However, in some instances, insurance authorization for bilateral implants must undergo medical review, with coverage decided on a case-by-case basis related to medical necessity (Peters, Wyss, & Manrique, 2010). Empirical studies investigating the affordances of bilateral versus unilateral cochlear implantation suggest improved sound localization and speech recognition in noise for bilateral implants, yet

¹ This is the typically referenced FDA criterion for pediatric implant candidacy; however, pediatric criterion do vary slightly by CI manufacturer.

further studies are needed to examine the cost-effectiveness as well as language and literacy outcomes associated with bilateral implantation (Johnston, Durieux-Smith, Angus, O'Connor, & Fitzpatrick, 2009; Zeng, 2004).

The CI consists of two parts: 1) an external speech processor, and 2) an internal device, which is surgically implanted behind the ear, consisting of a receiver and electrode array. Environmental sounds are picked up by the microphone of the external speech processor. The speech processor converts these acoustical signals into digital signals, which are then sent to the internal receiver via the transmitting coil. The internal receiver converts these digital signals into electrical signals, which are then sent to the electrode array located inside the cochlea. Various electrodes along the array are stimulated, sending an electrical signal directly to the auditory nerve, bypassing the damaged cells of the inner ear, and thereby allowing the brain to perceive sound.

Because of their capability to restore the ability to perceive and recognize sounds, CIs have the potential to reduce many of the barriers confronting individuals with significant hearing loss. However, it should be noted that CIs are a tool and not a “quick fix”; they cannot restore an individual’s hearing to “normal.” As with any medical prosthetic device, there are limitations. One reported device limitation relates to channel interaction associated with the spread of electrical current within the cochlea, which can hinder pitch perception (Deeks & Carlyon, 2004). In addition, CIs are limited in their ability to capture and transmit the fine temporal or spectral cues of complex acoustic stimuli, making the perception and production of intonation and other prosodic aspects of speech (i.e., suprasegmentals) challenging for CI users compared to individuals with typical hearing (Peng, Tomblin, & Turner, 2008). The limits of the device in coding a

complex acoustical signal into an electrical one have further implications for reduced speech understanding for CI users, especially in the presence of background noise and the appreciation of music (Zeng, 2004). Despite these limitations, many children and adults are able to utilize the sound percept they receive via the implant to support their language and literacy development.

For many pioneers in the field of implants, the affordances of CIs have far exceeded initial expectations (Niparko et al., 2010). Continued research and developments in device design and speech coding strategies hold much promise in further enhancing performance outcomes of both pediatric and adult CI users.

Theoretical Frameworks

In general, empirical studies of language and literacy acquisition in children with CIs have been primarily descriptive in nature. In such studies, the underlying theoretical frameworks were often implied rather than explicitly stated. Although many scholars acknowledged the relationship between children's language acquisition and later literacy development following cochlear implantation, how they understood or interpreted this general relationship, or the mechanisms that influenced this developmental trajectory, often differed.

Based on a review of the literature, I have identified three core underlying theoretical frameworks that have been used either explicitly or implicitly in the research on language and literacy development in children with CIs: 1) *Critical Period Hypothesis* (Lennenberg, 1967), 2) *Qualitative-Similarity Hypothesis* (QSH; Paul, 2009; Paul & Lee, 2010), and 3) *Transactional Model of Development* (Sameroff, 2009; Sameroff & MacKenzie, 2003). These three perspectives are not necessarily incompatible, but rather

represent differential foregrounding of key dynamics in children's language and literacy acquisition. I briefly discuss the underlying assumptions of these three theoretical frameworks, and how they relate to the study of language and literacy acquisition in children with CIs. Furthermore, these guiding frameworks will be revisited as I explore various factors associated with children's development after cochlear implantation.

Critical Period Hypothesis. Lenneberg's (1967) hypothesis of a critical period for language acquisition emphasized the role of nature or innate capabilities of the individual child in developing speech and language. Even though debate exists in the literature on whether the critical period ranges from birth to puberty or from birth to 5 or 6 years of age, most experts in the field would acknowledge that the first five years of life are the most crucial for auditory/oral language development (Ezell & Justice, 2005). When this hypothesis is applied to children with CIs, the underlying assumption is that early identification of hearing loss followed by early implantation capitalizes on the brain's neuronal flexibility inherent during this critical window or sensitive period of auditory-based learning supporting children's speech and language development (Niparko et al., 2010). Thus, if a child who is congenitally deafened receives an implant after this sensitive period, he/she would have relatively limited potential for language development compared to those implanted within the sensitive period.

This notion of a critical/sensitive period for language development has played a significant role in changing public policy to improve language and literacy outcomes in children with hearing loss. The federal government continues to support legislation to advance the development of states' Early Hearing Detection and Intervention (EHDI) programs. Such programs are designed to identify children with hearing loss during their

first year of life and to provide families with access to appropriate early intervention services in order to maximize children's learning potential. Additionally, proponents of the critical period hypothesis have been influential in lowering the Food and Drug Administration's (FDA) age requirement for pediatric cochlear implantation. From 1985 to the present, the required age for pediatric cochlear implantation has dropped from 5 years of age to 12 months of age since 2000, in part, to provide children access to auditory-based learning during this critical period for language acquisition.

There is some empirical support for the critical period hypothesis related to children with CIs. Zwolan, Ashbaugh, Alarfaj, Arts, & El-Kashlan (2004) conducted a study to examine the effect of age of implantation on children's speech perception outcomes. The study sample consisted of 295 children who were divided into five different age groups based on their age of implantation: 1-3 years, 3-5 years, 5-7 years, 7-9 years, and 9-11 years. Study findings revealed that all five groups demonstrated improved speech perception compared to their pre-operative scores obtained with hearing aids. However, children in the two youngest groups demonstrated greater gains in speech perception over time than those implanted at an older age, thus supporting the critical period hypothesis.

In a different study, Sharma, Dorman, and Spahr (2002) examined the neural plasticity of the central auditory pathways in children with congenital deafness following cochlear implantation compared to age-matched typically hearing peers. By examining the morphology and latencies of children's cortically evoked auditory potentials (CAEPs), the authors found greater plasticity of the central auditory pathways in children who were implanted at 3.5 years or less and significantly reduced neural plasticity in

children with the longest auditory deprivation (i.e. implanted at age 7 or older). These findings suggest a “use it or lose it” presumption in regards to maturation of the brain’s auditory pathways. The authors concluded that there appears to be a sensitive window for central auditory development following implantation in children who were congenitally deafened, highlighting the importance of early implantation to enhance speech and language development.

Qualitative-Similarity Hypothesis. Other researchers studying children with hearing loss have explained children’s developmental patterns in relationship to the various processes associated with language and literacy acquisition (e.g., phonemic awareness, speech perception, fluency, vocabulary, and reading comprehension) in typically developing children. Paul (2009) refers to this underlying theoretical framework as the *Qualitative-Similarity Hypothesis (QSH)*, in which the process and components of reading development are seen as qualitatively similar for children with hearing loss and children with typical hearing; however, progression tends to be quantitatively delayed in children with hearing loss.

This hypothesis posits that in learning English, as a first or second language, children with hearing loss, regardless of severity, proceed through stages, produce errors, and use strategies that are developmentally similar to what has been observed in individuals with typical hearing, thereby validating the use of mainstream literacy models for understanding and improving reading in children with hearing loss (Paul & Lee, 2010). The underlying assumption is that children who are deaf and hard of hearing may need specific instructional enhancements and additional intensive instruction compared to their typically hearing peers, yet the process and components of reading instruction

remain the same. The hypothesis also asserts that there is a reciprocity between spoken and written forms of English and acknowledges the importance of a strong foundation or working knowledge of the key components of English, including phonology, morphology, syntax, semantics, and pragmatics, to advance individual's language and literacy (Paul & Lee, 2010).

Debate exists among scholars as to whether children with hearing loss have developmental differences or similarities in language and literacy development compared to typically hearing peers. Yet, in studies of children with CIs, the *Qualitative-Similarity Hypothesis* (QSH) is often implicitly referred to as the underlying theoretical framework. Svirsky et al. (2000) investigated the rate of language development, measured by the Reynell Developmental Language Scale, in a group of children who were identified with a profound hearing loss prior to the age of 3 with the mean age at cochlear implantation of 4.5 years. They found that following cochlear implantation the rate of children's language development exceeded the expected developmental rate for deaf children without CIs and was comparable to children with typical hearing. The authors argued that cochlear implantation provides children with profound hearing loss with better access to perceive spoken words, and therefore, they are more likely to approximate typical oral language development. By providing greater access to acoustic-phonetic cues, CIs have the potential to narrow the developmental delay often observed in children with severe to profound hearing loss compared to their age-mates with typical hearing.

Transactional Model of Development. Other scholars have moved beyond merely examining the role that the individual child plays in her/his development and instead explore the complexities of language and literacy development within an

expanded social context. The seminal work of Hart & Risley (1995) identifies the role of the home environment in stimulating children's language and vocabulary development. Research has shown that family factors such as socioeconomic status, parents' education, family size, and parent interactions explained some of the variance in children's post-implant language and literacy acquisition (Connor & Zwolan, 2004; DesJardins & Eisenberg, 2007; Geers, 2002). Others have studied the role of educational placement or chosen mode of communication in relation to language and literacy outcomes in children with CIs (Connor & Zwolan, 2004; Geers, 2002; Geers et al., 2003).

In these instances, researchers have adopted a transactional model of development, which explores the dialectical relationship between nature and nurture as it relates to development. "What is core to the transactional model is the analytic emphasis placed on the bidirectional, interdependent effects of the child and environment" (Sameroff, 2009, p. 6). The child's environment is influencing the child's development, while at the same time the child is influencing their environment. For example, DesJardins and Eisenberg (2007) examined the relationship between maternal contributions and receptive and expressive language skills in young children with CIs during storybook reading. There was a bidirectional relationship where the mother's linguistic input was associated with the child's language skills, while at the same time the child's language skills influenced the mothers' mean length of utterance (MLU) (i.e., mothers of older children or children with higher language skills used more complex language during their storybook reading).

Integrating the frameworks. As demonstrated by these three underlying theoretical frameworks, both the cognitive and social aspects of language and literacy

acquisition have been examined by researchers studying children with hearing loss, including those receiving CIs. I would argue that there is validity in the arguments of proponents of all three perspectives. The research of Sharma and her colleagues (2002, 2005) examined the neurobiological changes in children's central auditory pathways and postulated a sensitive period for the development of these neural pathways after cochlear implantation. These studies demonstrated the effects of auditory deprivation on the development of auditory function, suggesting the importance of early implantation (i.e., 3.5 years of age or less) in children with congenital deafness. Therefore, researchers need to take into consideration the role of age at implantation when evaluating the effectiveness of CIs in fostering children's language and literacy acquisition.

In addition, I would argue that Paul's QSH (2009, 2010) applies to children with CIs, considering that these children tend to have greater auditory access to the sound structures of the English language compared to children with profound deafness without CIs. The QSH may be even more pronounced in children who undergo cochlear implantation as young as 12 months of age or younger (Ching et al., 2009; Vlastarakos et al., 2010) due to a shorter delay between the onset of hearing loss and stimulation of the central auditory pathways, enabling earlier exposure to speech sounds or phonology of the English language.

Paul and Lee (2010) argue for ongoing research on both the cognitive and social underpinnings of individuals' language and literacy development if we are to improve teaching and learning for children with hearing loss. There is a reciprocal relationship between cognitive and social underpinnings of a child's language and literacy development. Yes, early implantation during the sensitive period for the development of

the central auditory pathways is critical, but so too are the contextual factors (e.g., exposure to a language-rich environment) in further promoting children's language and literacy development. Hence there is a need to study contextual factors such as socio-economic status, parent-child interactions, and educational placement as they relate to the cognitive processes associated with language and literacy acquisition in children with CIs.

Language and literacy outcomes for children with significant hearing loss are improving as a result of cochlear implantation, yet delays still remain. With an elevated interest in CIs due to the promise that they hold for improved language and literacy, further research is warranted to examine the various factors of the individual child and his/her environment and how they might predict or influence language and literacy development after implantation.

Factors Influencing the Effectiveness of Cochlear Implants

To date, there is no method or prescriptive formula to predict with definitive accuracy a child's performance following cochlear implantation. As the literature has demonstrated, individual performance variability following cochlear implantation remains high (Zeng, 2004). There are many factors known to moderate the effectiveness of CIs in children. Some of these factors are related to the implant itself, as mentioned previously (e.g., channel interaction associated with current spread within the cochlea), while others are child-related (e.g., anatomical structure of the inner ear, onset of hearing loss, amount of residual hearing, and the child's level of cognitive functioning). Additionally, age of identification of hearing loss, age at implant activation, and contextual factors associated with educational services and family factors, such as parent

involvement and socioeconomic status, are known to affect children's performance after cochlear implantation.

Child factors.

Anatomy of the inner ear. Cochlear implantation is not indicated for children whose deafness is due to the absence or lesions of the acoustic (VIIIth) nerve or central auditory pathway. However, the anatomical structures of the inner ear can vary in children with intact auditory nerves. Buchman and colleagues (2004) examined the audiological and surgical outcomes in pediatric CI recipients identified with inner ear malformations (IEM), including those associated with an absent or malformed cochlea (i.e., isolated incomplete partitioning [IP] of the cochlea, Mondini's malformation, cochlear hypoplasia, and common cavities), and those associated with a normal cochlea (i.e., isolated enlarged vestibular aqueduct [EVA], and partial or total semicircular canal aplasia). Post-operative speech perception measures were obtained on 28 children identified with IEM. Results revealed that children with more severe inner ear anomalies (i.e., total semicircular canal aplasia, cochlear hypoplasia, isolated partitioning, or common cavities) had poorer speech perception outcomes than children in other IEM categories. On the other hand, the majority (86%) of children with Mondini's malformation, isolated EVA, or partial semicircular canal aplasia demonstrated functional speech recognition following cochlear implantation. However, the rate of development in speech perception was slower in children with IEM compared to children with typical cochlear anatomy. Other authors investigating congenital cochlear malformations (Eisenman, Ashbaugh, Zwolan, Arts, & Telian, 2001; Papsin, 2009) also

concluded that the majority of children presenting with cochlear malformations attained improved speech perception scores post-operatively.

Although the results of cochlear implantation may be promising for this sub-population of implant users, clinicians and surgeons need to provide parents of children with IEM realistic expectations regarding the variation in outcomes, especially if the child presents with common cavity, narrow internal auditory canal, total semicircular canal aplasia, or cochlear hypoplasia. Thus, researchers studying language and literacy outcomes in children with CIs need to decide whether to exclude these children presenting with cochlear anomalies or control for this as a confounding variable to accurately account for the variation observed in performance outcomes.

Onset of deafness and amount of residual hearing pre-implant. In regards to onset of deafness, it is important to consider whether the child's hearing loss occurred before (congenital or prelingual), during (perilingual), or after (postlingual) learning speech and language. Additionally, the effects of the age of onset of severe to profound hearing loss are confounded by the time between the onset of severe to profound hearing loss and when the child undergoes cochlear implantation. Children with CIs who acquired a severe to profound hearing loss postlingually have demonstrated higher language and literacy outcomes compared to those with congenital deafness (Geers, 2002, 2003). Children who present with congenital deafness have the potential to reach speech and language outcomes comparable to hearing peers following cochlear implantation; however, the earlier they receive their implant the better their postoperative performance (Connor, Hieber, Arts, & Zwolan, 2000; Connor & Zwolan, 2004; James, Rajput, Brinton, & Goswami, 2008). For those children with congenital deafness, the

longer the delay between the onset of deafness and cochlear implantation, the less effective the CI is likely to be in enhancing their language and literacy development. For children with postlingually acquired hearing loss, further research is needed to examine the relationship of the time between the onset of deafness and cochlear implantation and children's post-operative performance outcomes.

Related to the onset of hearing loss is the amount of residual hearing a child possesses prior to implantation. As the FDA candidacy criteria continue to expand, children with greater amounts of residual hearing are undergoing cochlear implantation. Empirical evidence has revealed that children with greater amounts of residual hearing have improved speech and language outcomes, compared to those presenting with profound hearing threshold levels (Nicholas & Geers, 2006; Zwolan et al., 2004). Greater amounts of residual hearing may be an indicator of improved neural survival available for electrical stimulation via the CI. In addition, consistent hearing aid use prior to implantation may have provided these children with limited, yet early auditory stimulation, more so than children with profound deafness, and this may have resulted in improved speech and language acquisition following implantation.

Cognitive functioning. In its report on the Annual Survey of Deaf and Hard-of-Hearing Children and Youth, the Gallaudet Research Institute (2008) indicated that approximately 40% of the children in the United States with some degree of hearing loss have additional disabilities. In the early years of determining pediatric implant candidacy, the presence of additional disabilities was considered a contraindication for cochlear implantation. However, in recent years, an increasing number of children with multiple disabilities are undergoing cochlear implantation (Donaldson, Heavner, &

Zwolan, 2004; Edwards, 2007). Speech and language outcomes may be limited and develop at a slower rate, compared to the general population of children receiving implants, yet the presence of additional disabilities does not automatically preclude these children from experiencing improved speech perception, communication gains, and overall improvement in quality of life (Berrettini et al., 2008).

In a review of the literature on children with additional disabilities who received CIs, Edwards (2007) reported that cognitive functioning was one of the strongest predictors associated with speech perception and speech production outcomes, following implantation in children with additional disabilities (i.e., the more severe the cognitive delay, the poorer the post-operative outcomes). Empirical evidence has shown that children with cognitive delays demonstrated improved speech and language acquisition following cochlear implantation, although the rate may be slower when compared to their typically developing implanted peers (Donaldson et al., 2004; Holt & Kirk, 2005; Pyman, Blamey, Lacy, Clark, & Dowell, 2000; Waltzman, Scalchunes, & Cohen, 2000).

Empirical evidence has also shown that concomitant cognitive delays can mediate the effectiveness of CIs in supporting children's language and literacy development. Thus, it is important for researchers studying language and literacy development in children with CIs to control for or take into consideration children's cognitive functioning as a variable of interest. This can be achieved with the inclusion of a psychological assessment measuring the child's nonverbal cognitive abilities conducted as part of the initial preoperative test battery or included as part of a postoperative follow-up battery. Geers et al. (2003) administered the WISC-III Performance Scale to study participants even though all 181 children in their original sample were reported to have normal

intelligence. They identified 24 out of 181 children who scored below the normal range (<85 standard score) on the WISC-III. Since this could contribute to poorer than expected language outcomes, the researchers decided to exclude these children from their analyses. After taking into consideration children's nonverbal cognitive abilities, study results revealed that of the remaining 157 children in their sample, 50% scored within an average range on several language measures. In addition, those children with higher nonverbal intelligence demonstrated higher levels of language development.

Another area of cognitive functioning that is currently being investigated by Pisoni and his colleagues is the role of working memory in explaining the variation observed in children's language and literacy development after cochlear implantation (Fagan, Pisoni, Horn, & Dillon, 2007; Pisoni & Cleary, 2003; Pisoni, Cleary, Geers, & Tobey, 1999). To process spoken language, children must utilize their working memory to act as the go-between for what they heard and the stored linguistic information in their long-term memory. Pisoni and his colleagues found that children with CIs performed more poorly on digit span measures compared to typically hearing age-mates. In addition, performance of working memory measures was correlated with speech, language, and literacy outcomes. This suggests the need to consider the role of working memory in moderating the effectiveness of CIs on children's language and literacy development. This area of research holds promise for furthering our understanding about language and literacy development in children with CIs. In addition, intervention studies focused on expanding children's working memory capabilities might provide insight on ways to enhance language and literacy development in children with CIs (Edwards, 2007).

Age of identification of hearing loss and age at implant activation. Hearing loss is the most common congenital birth defect, affecting 2-3 newborns out of every 1,000 born in the United States (Joint Committee on Infant Hearing, 2007). For newborns who are medically at risk (e.g., prematurity, cytomegalovirus [CMV] infection), the incidence of hearing loss is even higher. As mentioned earlier, hearing loss in children has been associated with delays in speech, language, literacy, academic achievement, and social/emotional development (Joint Committee on Infant Hearing, 2007). However, in recent years with the implementation of Universal Newborn Hearing Screenings (UNHS) and advances in medical technology (i.e., CIs and digital hearing aids), outcomes for children with hearing loss are improving.

Since the initial federal seed grants were awarded in 1999, state Early Hearing and Detection (EHDI) programs have made significant progress in ensuring that newborns receive hearing screenings within the first month of life. Results show a significant rise in the percentage of newborns screened prior to 1 month of age, from 46% in 1999 to 92% in 2005 (National Institute on Deafness and Other Communication Disorders, <http://www.nidcd.nih.gov/health/statistics/charts.htm>). Strides have been made in reaching EHDI Goal 2, which is diagnosis of hearing loss by 3 months of age, and EHDI Goal 3, which is to enroll children identified with a hearing loss in appropriate early intervention services by 6 months of age. As a result, an increasing number of children with congenital hearing loss are being diagnosed earlier, receiving hearing aids and/or CIs earlier, and enrolling in early intervention programs earlier than in years prior to the implementation of UNHS and state EHDI programs (White, 2003).

At the same time the federal government began providing funds to support state EHDI programs, the FDA reduced the required minimum age for cochlear implantation to 12 months. Both of these decisions were based on the notion of a critical period for developing language, where the earlier children are identified with hearing loss and receive intervention, the better their potential to reach speech and language outcomes commensurate to their typically hearing peers (Yoshinaga-Itano, Sedey, Coulter, & Mehl, 1998). Children are being identified with significant hearing loss earlier through UNHS and fitted with hearing aids as early as a few weeks of age. Both changes have led to children receiving CIs at a much younger age than in years past.

Several empirical studies have examined the relationship between age at implantation and language and literacy outcomes in children with CIs (e.g. Connor & Zwolan, 2004; Connor et al., 2006; Nicholas & Geers, 2006; Tomblin, Barker, Spencer, Zhang, & Gantz, 2005; Zwolan et al., 2004). Age at implantation has been studied as an independent variable in examining children's post-implant performance on measures of phonological awareness, speech perception, oral language, vocabulary, and reading. In general, the findings of these studies suggest that the earlier a child receives an implant, the better their performance outcomes. Sharma and her colleagues (2002, 2005) examined the role of age at implantation on the development in children's auditory systems, which affect children's language and literacy learning. They found that children with prelingual deafness who received their implant at 3.5 years of age or less showed age-appropriate cortical auditory evoked potentials within six months after implant activation, which was not the case in children implanted after the age of 7 years. These findings suggest a critical window for the development of the central auditory pathways

for children with congenital hearing loss, indicating the importance of early implantation in children with prelingual deafness.

Examining the effects of age at implantation on children's language and literacy outcomes is a complex task because the child's age, length of device use, onset of hearing loss (i.e., pre- or postlingual), and age at implantation are highly correlated (Connor et al., 2006). Researchers need to consider these inter-relationships when studying the effects of age at implantation on children's language and literacy outcomes. For example, if a study on the effect of age at implantation on language outcomes includes children who were prelingually and postlingually deafened, it is important to consider the onset of deafness as a potential confounding factor, as children implanted after the development of speech and language tend to be higher performers. Studies that do not take this into consideration are at risk for mistakenly identifying causal relationships of predictor variables.

Contextual factors.

Educational or communication approach. Research has revealed that children who were identified with hearing loss by 6 months of age and received early intervention had significantly better speech and language outcomes compared to children whose hearing loss was identified after 6 months of age (Yoshinaga-Itano et al., 1998). However, what is classified as appropriate early intervention continues to arouse much debate, especially in children identified with severe to profound hearing loss. Should educational interventions use an auditory approach (i.e., auditory-oral, auditory-verbal, or cued speech) or an approach that is more visual—that is, using sign language (i.e., total communication, Signed Exact English [SEE] or American Sign Language [ASL])?

Should the approach be different for children prior to implantation versus after implantation?

Empirical evidence in this area suggests that children who utilize or are educated using either an oral or sign (or total communication) approach both benefit from CIs (Spencer & Marschark, 2003). However, children who use an auditory-oral approach tend to acquire speech and language skills at faster rates and demonstrate higher overall language achievement levels than their implanted peers who use a sign or total communication approach (Connor & Zwolan, 2004; Geers, 2002; Geers et al., 2003). Because the purpose of the implant is to provide improved sound perception to support children's language and literacy acquisition, dependence on speech and audition for communication following implantation is essential.

Educational or communication approach can also mediate the effectiveness of CIs in children. Yet, how researchers define primary mode of communication or educational approach as a variable of interest can be challenging as children with CIs often move in and out of educational placements based on their performance. Some children may begin using a total communication approach prior to implantation, and then once their speech and language development improves, they move into a setting using an oral approach, while other children use an oral approach both pre-and post-implant. Furthermore, there are children who use a total communication approach in their educational setting but an oral approach in their home setting. Children's primary mode of communication or combination of modes is important to keep in mind when designing or interpreting studies of the effects of language modality on children's language and literacy outcomes.

Another area to consider, which is related to the child's primary mode of communication, is how language and literacy measures are administered to children pre- and post-implant. The purpose of the implant, a sensory device, is to provide greater access to the auditory pathways; therefore, some researchers assess children using an auditory-only mode (i.e., listening only, no additional cues from lip-reading, cueing or sign language). Other researchers choose to conduct their assessments using an auditory-visual approach (i.e., audition+ lip-reading, with or without signing). This too is important to keep in mind when designing or interpreting studies of the effects of mode of communication or educational approach on children's language and literacy development.

Family factors. It has been well documented that early language and literacy development is associated with children's experience with language in the home (Hart & Risley, 1995; Neuman & Dickinson, 2001; Snow, Burns, & Griffin, 1998). However, few studies of children with CIs examine the role of the home on children's language and literacy outcomes. In order to maximize the affordances of the implant, family involvement is critical to ensure the child attends follow-up programming and speech therapy appointments, that the child's external speech processor is functioning appropriately, that consistent device use is established, and that the child is immersed in a language-rich home environment. In a study investigating language and literacy outcomes in 181 8- and 9-year-old children at four years post-implant, Geers (2002) asked parents to complete a questionnaire to estimate the frequency with which they participated in activities designed to stimulate their child's auditory and speech development in the home. Findings showed that on average, parents reported working

with their child on a daily basis the first two years after implantation and then between a daily or weekly basis during the third and fourth year. However, no further discussion on how this related to children's language and literacy development was addressed.

Geers et al. (2003) conducted another study with the same cohort of 181 children with CIs and their families to further examine the relationship between family characteristics and children's speech and language outcomes. In particular, the researchers examined family size (i.e., number of family members in the home) and socioeconomic status (SES), which was a combined rating of family income and parents' education. They found that higher SES and a smaller family size were associated with higher scores on children's performance on speech perception, speech production, and language measures after cochlear implantation. In a different study, Connor and Zwolan (2004) examined the role of SES on children's reading comprehension following cochlear implantation. Unlike the previous study, SES was determined by the family's medical insurance coverage. Those who qualified for Medicaid or state-funded insurance were considered low SES, while children whose family had private insurance with or without state-funded insurance were classified as middle SES. Study findings showed that reading comprehension in children of low SES families were significantly lower when compared to outcomes in children from middle SES families. As observed in children with typically hearing, family factors, such as SES, can affect language and literacy outcomes in children with CIs.

Overall, research investigating the relationship between family factors and children's performance after cochlear implantation is sparse. If we are to understand the variance observed in children's post-implant performance, further research is needed to

evaluate the role of family factors on children's language and literacy acquisition.

Summary: Moderating Factors on the Effectiveness of CIs

Empirical evidence has shown that there are multiple moderating factors either associated with the child, the implant device itself, or contextual issues, that can affect children's language and literacy outcomes after cochlear implantation. Factors related to the child such as inner ear anatomy or amount of residual hearing pre-implant cannot be changed, but are important to take into consideration when evaluating language and literacy acquisition in children with CIs. The presence of an inner ear malformation or additional disabilities does not necessarily preclude a child from being a CI candidate; however, such factors can limit the amount of benefit received by the CI in fostering their language and literacy development. As a result, parents need to receive appropriate counseling preoperatively to provide them with realistic expectations regarding their child's outcomes following cochlear implantation.

In addition to considering moderating factors related to the implant device or child, additional factors such as age at implantation, mode of communication, and family factors are important to consider when evaluating language and literacy development in children with CIs. In 2000, the FDA lowered the minimum age of implantation to 12 months of age; therefore, the first cohort of recipients to receive an implant prior to their second birthday is just approaching 9 to 10 years of age. Minimal research exists on this younger generation of CI users. Further insight can be gained from research examining how this younger generation of pediatric CI users compares in language and literacy development to the literature on children who were implanted at a much later age. There are other contextual factors (e.g., surgical expertise, clinicians' expertise in device

programming, and educational professionals' expertise in working with children with CIs) that can influence performance outcomes in children with CIs. Even though these may be difficult to measure, they too warrant further investigation in order to maximize performance outcomes in children with CIs.

It is undoubtedly challenging to consider all these confounding factors and their effect on children's language and literacy development after cochlear implantation. In addition, many of these factors are inter-related, and their interactions are not fully known. Continued research designed to study and clarify the nature of these interactions will advance the field of pediatric cochlear implantation and, ultimately, improve performance outcomes in children after cochlear implantation.

Language and Reading Development

From the literature on children with hearing impairment and typical language and literacy acquisition, we know that phonological awareness, word reading, oral language, fluency, and comprehension skills are important components of children's language and literacy learning (NICHD, 2000; Schirmer & McGough, 2005). In this section, I review the literature and present a theoretical argument for considering why these areas are important to investigate in regards to language and literacy development in children with CIs.

The ability to read words, quickly, accurately, and effortlessly is necessary to develop skillful reading comprehension (Adams, 1990). Because English is a speech-based writing system, it is important for children to come to learn and understand the relationship between spoken and written language. Adams (1990) proposed a developmental model of reading which identifies the reciprocal relationships between

three key processors: 1) Phonological Processor (knowledge of the sound structures of a word), 2) Orthographical Processor (knowledge of the written word), and 3) Meaning Processor (knowledge of a word's meaning). In addition, Adams suggested a fourth processor, Context Processor (knowledge of the context in which a word occurs), which has a reciprocal relationship with the Meaning Processor. In theory, when these processors are working together, automaticity in word recognition is enhanced, thus enabling greater cognitive energy to be dedicated to support reading comprehension. As children begin to develop into skillful readers, the relationships among these processors become more complex as each one guides and reinforces the growth of the other.

The second major area of development that will affect children's reading comprehension is their language comprehension. There is considerable research to demonstrate that children's reading comprehension can be no better than their language comprehension. This is particularly evident with children who have language impairments (Snowling, 2005), but it is also apparent in children who are hearing impaired (Vermeulen, van Bon, Schreuder, Knoors, & Snik, 2007). Theories of reading comprehension suggest that language comprehension is a major contributor to effective text comprehension, particularly as students get older (Scarborough, 2001). Researchers have been able to identify different subgroups of poor readers in studies that do not include children with hearing impairment, and have shown that some children do have specific language or listening comprehension problems, while others have both decoding and language comprehension problems (Catts, Hogan, & Fey, 2003). The fact that these two aspects play a significant role in supporting children's reading comprehension is important to consider in children with CIs.

Based on Adam's model, children with hearing loss are at risk for reading difficulties because their limited access to the sound structure of words limits the effectiveness of their Phonological Processor as a support for reading acquisition. Empirical evidence has shown that some deaf children are able to access the Phonological Processor through non-auditory pathways such as speech-reading, orthographical cues, articulation movements, or fingerspelling to support their reading development (Hanson & Fowler, 1987; Kyle & Harris, 2006; Leybaert, 1993; Perfetti & Sendak, 2000). However, cochlear implants enable children with significant hearing loss with greater access to the sound representations of words than ever before, and thus it is important to consider the extent to which children with CIs develop speech perception that is similar to that of their typically hearing peers. Does the implant provide children with a complete or distinct representation of the phonological structure of words to develop age-appropriate speech, language, and literacy skills? I hypothesize that children with CIs may not have access to the full representation of the sound structure of words due to limitations of the CI device itself (i.e., inability to capture the fine temporal or spectral cues of a complex speech signal). Furthermore, when considering the sensitive period for the development of children's central auditory pathways, as suggested by the research of Sharma and her colleagues (2002, 2005), access to the full representation of the sound structure of words may be highly dependent on children's onset of hearing loss (i.e., acquired or congenital), age at implantation, and their access to sound pre-operatively (i.e., residual hearing) and post-operatively (i.e., CI hearing threshold levels).

An incomplete phonological representation of words may affect children's development of phonological awareness and their learning to read words. In addition, as

we shall see, because of the known relationship between phonological awareness and vocabulary, limited development of phonological awareness may stand in the way of children's vocabulary acquisition. Without a full representation of the sound structure of words, then, children may have difficulties with word reading and vocabulary development, which in turn ultimately limits their reading comprehension (Elbro, Borstrom, & Petersen, 1998; McBride-Chang, 1995; Perfetti, 2007). Hence, there still remains a critical unanswered question: to what extent are CIs beneficial in terms of supporting children's language and literacy development?

Speech perception and speech production. The premise of cochlear implants is to provide children with severe to profound hearing loss with greater access to auditory stimuli, which can lead to enhanced speech perception, in turn, supporting oral language development and literacy acquisition. There is value in determining speech perception capabilities in children following cochlear implantation, yet equally important is to understand whether improved speech perception via the implant is enough to provide the kinds of high quality representations that are beneficial to support children's language and literacy learning. Several studies have demonstrated the effectiveness of CIs in improving children's speech perception capabilities over time (e.g., Geers, 2003; Geers et al., 2008; Tyler et al., 1997; Zwolan et al., 2004).

Extending one of their early studies, Geers and colleagues (2008) examined speech perception abilities in 85 CI users who had an onset of deafness prior to age 3 and received their implant by age 5 ½. The researchers compared children's performance assessed at age 8 and 9 to their speech perception abilities as adolescents. The results showed that overall, children's speech perception scores improved significantly with

long-term implant use. They noted that children with better speech perception outcomes in the early elementary years continued to show an advantage in high school. In addition, improved performance in adolescence was associated with lower pure-tone average CI thresholds. This may be associated with the fact that children with lower implant threshold had updated speech processors. However, this finding has additional clinical and theoretical implications, highlighting the importance of routine sound field testing to verify appropriate device programming and microphone quality in order to maximize children's detection of sound (i.e., access to the phonological structure of words) via the implant.

Other work in this area conducted by Zwolan and her colleagues (2004) has focused more specifically on the effect of age at implantation on children's speech perception outcomes over time. Overall, the researchers found that regardless of their age at implantation, study participants demonstrated improved speech perception abilities, compared to their scores obtained preoperatively with hearing aids. However, children in the two youngest groups (i.e., implanted between 1-3 years or 3-5 years of age) made greater gains in their speech perception skills compared to the later-implanted groups.

Similar to Zwolan et al.'s longitudinal study, Svirsky, Teoh, and Neuburger (2004) examined the effect of age at implantation on CI outcomes in children who were prelingually deafened, yet received their implant prior to the age of 5. The researchers divided children into three age groups, based on age at implantation (i.e., 16-24 months, 25-36 months, and 37-48 months) for their analyses. Comparison of outcomes between the three groups was performed using developmental trajectory analysis, which examined the growth curves in children's speech perception performance over time. Study

participants were tested between 2 and 8 times, with the initial assessment occurring prior to the initial activation of the implant. There was at least 6 months between additional testing sessions. Children who were implanted prior to the age of 2 demonstrated a significant advantage in speech perception development over time, compared to those implanted between 3-4 years of age. Zwolan et al. (2004) and Svirsky et al. (2004) hypothesized that providing an implant at an early age maximized the stimulation of the central auditory pathways during a sensitive period, enhancing the development of children's speech and language skills. Research has shown improved speech perception outcomes for children with CIs; however, the question still remains as to whether "better" speech perception following implantation leads to what Elbro et al. (1998) and others refer to as access to high quality phonological representation of words.

Another issue that researchers have examined is the relationship of speech perception and speech production in children with CIs. In children with typical hearing, speech production is an important indicator of speech perception and phonological representations (Levelt, 1992). O'Donoghue and colleagues (1999) investigated this relationship in 126 children who had an onset of profound hearing loss under the age of 3 and received their implant by age 7. Children's speech intelligibility scores at 5 years post-implant were highly correlated with their speech perception scores at 2, 3, 4, and 5 years post-implant. These results suggested that children with better speech perception over time were likely to have better speech intelligibility. Perhaps of greater relevance are the results of a longitudinal study carried out by Connor et al. (2000), which examined the effects of age at implantation on children's performance on consonant-production tasks. Children who were implanted at a younger age (i.e., < 5 years)

achieved higher scores and significantly greater growth rates in consonant-production than did children who received their implant after age 5.

These two studies have identified a particular benefit of cochlear implantation for children with severe to profound hearing loss, but again “better” speech production does not necessarily address the issue of whether children have access to a complete phonological representation of words. Speech intelligibility is an important indicator of speech perception and phonological representations, yet incomplete perceptions or phonological representations may lead to deficits in phonological processing skills, including phonological awareness, the mapping of phonemes to graphemes in word reading, and verbal short-term memory, leading to deficits in reading ability (McBride-Chang, 1995).

Phonological awareness and phonological processing. Speech perception contributes to children’s phonological development, which plays a role in the development of phonological awareness—that is, sensitivity to the sound structure of words, as shown by children’s ability to analyze and manipulate the sound structure of words. Research with hearing children has shown the importance of phonological awareness in the development of decoding, fluency, vocabulary learning, and reading comprehension (Goswami & Bryant, 1990; NICHD, 2000; Snow et al., 1998). One hypothesis for the relatively poor reading ability of children who are deaf and hard-of-hearing relates to the inadequacies in phonological processing due to children’s limited ability to hear and manipulate the sound structures of words (Musselman, 2000).

James and her colleagues (2005, 2008, 2009) have studied the degree to which cochlear implantation supports the development of phonological awareness in children

with severe to profound hearing loss. These researchers also examined the role of orthography in the development of phonological awareness. They designed their own battery of tests, using picture identification to investigate syllable, rhyme, and phoneme awareness in children with CIs. These tasks were designed to examine the extent to which orthographic knowledge influenced children's phonological judgments. Syllable, rhyme, and phoneme trials were created so that an equal portion of trials were orthographically congruent and orthographically incongruent. For example, the phoneme task was designed to assess children's awareness of phonemes in the word-initial position. Half of the trials included pictures representing objects whose written form had the same initial phoneme in both the target and cue, thus orthographically congruent, as in the pair, *f*inger/*f*ox, while the remaining trials were orthographically incongruent, as in the pair, *q*ueen/*c*ot (see James et al. 2005, for further explanation).

In their initial study, James et al. (2005) compared outcomes on measures of phonological awareness between children with implants (mean age, 8.4 years) who received their implant prior to age 7 and two groups of children with hearing aids—a severe hearing loss group (mean age, 7.4 years) and a profound hearing loss group (mean age, 9.5 years). Children with CIs had better performance on syllable awareness than rhyme and phoneme awareness. On syllable awareness, their performance was similar to that of children with severe hearing loss using hearing aids, yet rhyme and phoneme awareness were equivalent to that of children in the profoundly deaf group using hearing aids. However, over the course of the one-year study, the authors observed that in children with CIs, awareness of syllables and rhymes preceded awareness of phonemes, demonstrating a similar developmental sequence to that of children with typical hearing

(Fowler, 1991). As we shall see shortly, the fact that they are similar to children with hearing loss without CIs may have to do with the age at implantation.

Another issue addressed by James and colleagues (2005) was the degree to which children with CIs used their orthographic knowledge to aid their phonological judgments. In theory, the use of written-language representation should support awareness and memory for distinctions of sound. The study findings demonstrated significant improvement over time in the CI group's performance on the orthographically incongruent rhyme trials, yet these children tended to rely more on their orthographic knowledge when making syllable and phoneme judgments. The authors argued that these findings suggest that phonological awareness (PA) and orthographic knowledge develop concomitantly in children with implants, and that utilizing children's orthographic knowledge in the development of PA may lead to improved language and literacy outcomes in children with profound hearing loss.

This initial work was extended to examine the effect of age of implantation on phonological awareness (James et al., 2008). As observed in studies of speech perception and speech production, children who were implanted between 2 and 3 ½ years of age had better performance outcomes on phonological awareness than those children in the later-implanted group (i.e., implanted between 5 and 7 years). Furthermore, children in the earlier-implanted group, more so than the later-implanted group, had phonological awareness performance scores on syllable, rhyme, and phoneme tasks (see James et al., 2005) that fell within the standard distribution of reading-matched children with typical hearing.

Other research in this area by Spencer and Tomblin (2009) has taken on a broader view by examining the relationship of phonological processing (PP) skills (i.e., phonological awareness, phonological memory, and rapid naming) and word reading abilities in children with CIs. Study participants included 29 children with prelingual hearing loss who received an implant prior to the age of seven years and 29 children with typical hearing. The groups were matched based on mother's education and word comprehension ability. Various subtests of the Comprehensive Test of Phonological Processing (CTOPP; Wagner, Torgesen, & Rashotte, 2001) and the Woodcock Reading Mastery Test (WRMT; Woodcock, 1987) were used to assess children's phonological processing and reading skills.

One goal of the study was to establish valid measures for assessing PP skills in children with hearing loss, as assessment outcomes may be confounded by children's listening and speech production abilities. Hence, the researchers designed their study to evaluate the difference in children's PP skills using two presentation modes (i.e., auditory-only (A/O) and auditory-visual (A/V)). For the blending and non-word repetition tasks, children's abilities were measured first by having them watch and listen to the examiner (i.e., A/V condition) and then again by having them listen to an audio file played through computer speakers (i.e., A/O condition). In addition, to reduce the effect of CI user's speech perception and speech production abilities on measures of memory (i.e., digit recall task), researchers included visual representations of digits on a computer screen, paired with auditory presentation, and children provided their responses using the computer's keyboard, instead of voicing their response.

Overall, the study findings revealed that PP skills correlated with children's word recognition and word comprehension. Performance on phonological awareness tasks (i.e., elision, blending, and rhyme) in children with CIs showed a longer developmental phase before obtaining mastery than was observed in children with typical hearing, and a large variation in performance existed among children with CIs. The authors hypothesized that the reciprocal relationship between PA and reading (i.e., PA is reinforced by reading) may be more evident in children with CIs than in children with typical hearing. Because children with CIs have a limited representation of the sound structure of words, exposure to words in print may be more beneficial in supporting their development of PA. In regards to phonological memory and rapid naming, there were no differences observed between performances of the CI group and hearing controls when assessed using an auditory-visual presentation. When assessing children using an auditory-only presentation, children's speech perception may be affecting the results, potentially underestimating their PP skills. The results of this study indicated that PP skills in children with CIs could be assessed, but that using an auditory-visual condition may provide a more valid measure of children's PP skills. These findings have educational implications, as they suggest the role of auditory-visual cues (i.e., speech-reading) and written (i.e., orthographic) cues to promote a more complete representation of the phonological structure of words to support language and literacy learning in children after cochlear implantation.

Word recognition. Research involving children with typical hearing has identified that many children who are struggling readers in the early elementary years have difficulty associated with their ability to recognize words in print (Scarborough,

2001). Children's phonological awareness, decoding abilities (i.e., ability to apply one's knowledge of letter-sound and spelling-sound relationships to correctly pronounce the printed word), and sight recognition (of familiar words) are important components of children's word recognition abilities, which influence their ability to become a skilled reader. Interested in investigating word reading skills in children following cochlear implantation, Vermeulen et al. (2007) compared measures of visual word recognition in 50 Dutch children with CIs who were at least 7 years old and had at least 3 years of CI use to reference data of 500 children with profound hearing loss without CIs and a group of children with typical hearing, matched for instructional-age. The researchers decided to use instructional-age to adjust for the amount of formal reading instruction a child had received. Children were assessed using two lexical decision tasks from an earlier study conducted by Wauters, van Bon, and Tellings (2006). Results of the study showed that children with CIs did not differ in their visual word recognition skills from those in the hearing control group; however, deaf children without CIs had visual word recognition skills below those children with typical hearing.

In another study, Geers (2003) administered the Word Attack subtest of the WRMT (Woodcock, 1987) and the Reading Recognition and Reading Comprehension subtests of the Peabody Individual Achievement Test (PIAT)-Revised (Dunn & Markwardt, 1989) to assess children's word recognition and reading comprehension after cochlear implantation. Study participants included 181 children who were between 8 and 9.11 years of age and had 4 to 6 years of CI experience. Results revealed a strong correlation ($r = .85$) between pseudoword (i.e., Word Attack subtests) and real word recognition scores (i.e., Reading Recognition subtest), and both were highly correlated

with children's reading comprehension scores, revealing a positive relationship between word reading and reading comprehension in children with CIs—as has also been observed in children with typical hearing. Over half of the children with CIs in this study achieved reading scores within the average range for hearing children their age, which is promising. However, the authors noted considerable variability in reading outcomes among children with CIs.

Continued research designed to examine the relationships between children's speech perception, speech production, phonological processing, orthography, and word recognition abilities on their language and literacy development may provide insight into the variation in performance observed in children after cochlear implantation. Gaining a greater understanding of these relationships may lead to potential interventions to support children's language and literacy development after cochlear implantation.

Language comprehension and vocabulary. Because CIs can provide children with profound hearing loss with improved access to auditory stimuli, it is presumed that this, in turn, will provide them with greater opportunity to develop oral language skills, including enhanced vocabulary development. Empirical research has shown that some children with severe to profound hearing loss who have undergone cochlear implantation are reaching language skills commensurate with their typically hearing peers (e.g., Geers et al., 2003; Spencer, Barker, and Tomblin, 2003; Svirsky et al., 2000). In a study of 16 children with CIs and a control group of 16 age-matched children with typical hearing, Spencer et al. (2003) found that children in the CI group performed within one standard deviation of the hearing controls on measures of language comprehension (i.e., Concepts and Directions subtest of the Clinical Evaluation of Language Fundamentals –III [CELF-

3]). Geers et al. (2003) found that more than half of their 181 study participants who received their implant prior to age five exhibited language skills at age 8 and 9 that were commensurate with hearing peers on measures of verbal reasoning, narrative ability, utterance length, and lexical diversity. Additionally, higher nonverbal intelligence, smaller family size, and higher SES were associated with improved language ability post-implant. After controlling for the aforementioned child and family mediating factors, the researchers found that the amount of time spent in a mainstream classroom and an oral education focus were associated with children's linguistic outcomes post-implant.

Following this cohort to understand how the implant affected their language learning over time, Geers and her colleagues (2008) reassessed children's language outcomes in high school and found that children's performance at that later point in time was strongly predicted by their language factor score obtained in the elementary years. Children's language factor score was derived by combining their verbal IQ scores with their standard scores on measures of expressive and receptive vocabulary as well as language comprehension. Children with higher performance IQs and an earlier age at implantation demonstrated greater language gains over time. Furthermore, there was a positive association with early oral education on children's language outcomes after implantation in both the elementary and high school years, even though the advantage did not increase from the early elementary years to high school.

Other researchers have examined the role of age at implantation on children's language development after cochlear implantation. Svirsky et al. (2004) conducted a longitudinal study of children who received their implant prior to the age of 5 years. The participants were divided into three groups, based on age of implantation; however, the

groupings differed only slightly in age (i.e., implanted between 16-24 months, 25-36 months, and 37-48 months). Children's language skills were measured using the expressive section of the Reynell Developmental Language Scales (RDLS, Edwards et al., 1997) and were recorded as age-equivalent scores; if the RLDS could not be administered, children's language age was predicted based on their performance on the MacArthur Communicative Development Inventories (MCDI; Fenson, et al., 1993). Study findings showed that implantation prior to age 2 resulted in improved language skills, compared with children who received their implant after age two. Tomblin et al. (2005) also found that children implanted as infants had more rapid expressive language growth, as measured by the Minnesota Child Development Inventory and Preschool Language Scale-3, than those implanted as toddlers. The authors argued that implantation in early infancy allowed for children with implants to take advantage of the reciprocal relationship between the neurobiological development of the central auditory pathways and experience, thus enhancing children's overall language development.

In a recent study, Niparko et al. (2010) examined spoken language outcomes of children who were implanted prior to the age of 5 ($n = 188$) and their typically hearing peers ($n = 97$) over a 3-year period. Study participants' spoken language comprehension and expression was measured using the Reynell Developmental Language Scales (RDLS, Reynell & Gruber, 1990). Interested in the effects of age at implantation on spoken language outcomes, the authors stratified children into three groups (i.e., implanted younger than 18 months, 18-36 months, and older than 36 months). Study findings demonstrated that overall, children with CIs had slower and more variable language trajectories than those children with typical hearing. Children who received their implant

prior to 18 months had significantly higher rates of development in language comprehension and expression than those who were later-implanted. Furthermore, the early-implant group had language trajectories that paralleled those with typical hearing, while the gap in language development widened over time between children implanted after 18 months compared to their typically hearing peers. In addition to age at implantation, the researchers found that greater residual hearing pre-implant, higher ratings of parent-child interactions, and higher SES were associated with greater rates of language comprehension and expression in children after cochlear implantation.

Another important area of language to assess in children with CIs is their vocabulary development. This is not only because vocabulary contributes to children's overall language competency, but also because it relates to children's development of reading (Adams, 1990; Scarborough 2001). In a study of children's vocabulary growth curves and rates of growth over time, Connor et al. (2006) found an additional added value for earlier implantation on vocabulary development beyond the typical advantages associated with longer length of device use. The researchers studied 100 children who had undergone cochlear implantation between 1 and 10 years of age, with mean age of device use of 4 years. Children were divided into four groups based on age at implantation: implanted between 1 and 2.5 years, 2.6 and 3.5 years, 3.6 and 7 years, and 7.1 and 10 years. Children's receptive vocabulary skills were measured using the Peabody Picture Vocabulary Test 3 (PPVT-3; Dunn & Dunn, 1997). PPVT scores were available for all study participants, with a mean of four assessments for each child.

Children who had received their implant prior to 2.5 years of age demonstrated earlier bursts of growth in vocabulary as well as better vocabulary outcomes, compared

with those children who received their implants at a later age. The early burst of vocabulary was not observed for children implanted after 3.5 years of age, and the rate of vocabulary growth diminished systematically with increasing age at implantation. This finding provides support for the theory of a sensitive period for language development and relates closely to the findings of Sharma et al. (2002), who demonstrated greater plasticity of the central auditory pathways in children who were implanted at 3.5 years or less. The authors argued that continued efforts for early identification and implantation in children with significant hearing loss is crucial because of the relationship between age of implantation and speech production and spoken vocabulary growth, as well as the ensuing consequences for speech and language acquisition.

A study by Hayes, Geers, Treiman, and Moog (2009), conducted to examine children's receptive vocabulary growth over time, corroborated the findings presented by Connor and her colleagues and demonstrated that children who were younger (i.e., implanted under the age of 2) had the potential to achieve receptive vocabulary skills commensurate with typically hearing peers within a few years following implantation. In this study, 65 children who were implanted under the age of five were assessed annually using PPVT-R or PPVT-III. On average, children were assessed three times, roughly one year apart. Study findings showed that children with CIs had lower receptive vocabulary skills than their hearing peers; however, they demonstrated substantial vocabulary growth over time, making more than a year's progress in a year's time; narrowing the gap between their performance and that of their peers with typical hearing. Additionally, early-implanted children had steeper growth rates than children in the later-implanted group, as was also noted by Connor and her colleagues (2006).

In summary, research has shown that CIs provide children with significant hearing loss with better access to spoken language, which has enabled children with implants to develop language comprehension and vocabulary better than that observed in children with profound hearing loss without CIs. Furthermore, research has demonstrated that children (prelingually deafened) who underwent cochlear implantation at an early age (<5 years) had greater potential to reach age-appropriate speech and language skills than those who received their implant later in life. In addition to age at implantation, various child (i.e., amount of residual hearing), family (i.e., SES), and educational factors (i.e., oral education) influenced language outcomes.

Reading comprehension. In the studies that have examined achievement in reading comprehension, results suggest improved outcomes in children with CIs in comparison to deaf children without CIs, yet many children still remain delayed in their reading comprehension when compared to their typically hearing peers (e.g., Connor & Zwolan, 2004; Geers, 2002, 2003; Geers & Hayes, 2011; Spencer, Tomblin, & Gantz, 1997; Vermulen et al., 2007). Spencer et al. (1997) found that nearly half of their study participants were reading at or within 8 months of their grade-level on the Passage Comprehension subtest of the Woodcock Reading Mastery Test-Revised (WRMT-R). Study participants included 40 children with prelingual deafness who were implanted between 2 and 13 years of age with at least 2 years of CI experience. In a later study, Spencer and colleagues (2003) investigated the relationship between language and literacy outcomes in 16 prelingually deafened pediatric CI users who received their implant between the ages of 30-76 months and then compared their performance to typically hearing age-matched peers. Expressive and receptive language skills were

assessed using the CELF-3, and reading comprehension was assessed using the Passage Comprehension subtest of the WRMT-R. Study findings revealed that children with CIs performed within one standard deviation of the hearing controls on measures of language comprehension and reading comprehension. In addition, there was a strong correlation ($r = .80$) between language performance and reading performance in children with CIs. These results suggest that better language skills were associated with improved reading comprehension; a similar developmental relationship to that of children with typical hearing (NICHD, 2000).

Geers (2003) conducted a study to examine language and literacy outcomes in 181 8- and 9-year-olds who were deafened prior to age 3 and received their implant prior to 5 ½ years of age. Children's reading comprehension abilities were measured using the Peabody Individual Achievement Test (PIAT) - Revised. Over half of the children (52%) demonstrated total reading scores within the average range of their peers with typical hearing. However, the author noted considerable variability among children with CIs, some exhibiting minimal reading development. Characteristics of better readers included higher performance IQs, female gender, more highly educated parents (proxy for SES), and later onset of hearing loss (between birth and 3 years of age). In addition, Geers found that children who had longer use of an updated speech processing strategy (i.e., Spectral Peak (SPEAK) coding strategy) and a larger electrical dynamic range (i.e., range between soft and loud percepts in their implant mapping) presented with improved reading capabilities. Thus, features of the implant device itself may provide children with greater auditory access to the sound structures of the speech signal, thereby supporting children's speech, language, and literacy development.

Geers and colleagues (2008, 2011) conducted a follow-up study with 85 and then 112 of the original 181 children who participated in their original study to examine the long-term outcomes of cochlear implantation, comparing children's outcomes in the elementary grades to those obtained in high school. In both studies, outcomes on high school language and literacy measures were best predicted by children's previous scores obtained in early elementary school; the better performers at age 8 and 9 maintained this advantage in high school. In general, the researchers found that children's speech perception and language scores improved with long-term implant use, yet their reading skills developed at a slower rate than those of their peers with typical hearing. The majority of the students with CIs did not reach age-appropriate reading comprehension in high school; however most of the students (72%) maintained their reading levels over time compared to their hearing peers, indicating that the reading performance gap did not widen over time. Additionally, higher non-verbal intelligence, later onset of deafness, better phonological processing skills, and educational emphasis on spoken language were associated with better language and literacy performance in high school.

Interested in the relationship of children's speech perception and production skills on reading comprehension outcomes, Spencer and Oleson (2008) conducted a study of 72 children with prelingual deafness who received their implant between 1.1 and 7.3 years of age (mean = 3.6 yrs). The researchers assessed children's speech perception and production abilities after at least 4 years of CI use. Children's reading competency was later assessed after 7.5 years of CI using the Word Comprehension and Passage Comprehension subtests from the WRMT-R. The researchers found that 59% of the variance in word comprehension and 62% of the variance in passage comprehension was

explained by children's early speech perception and speech production performance. The authors hypothesized that early listening and speaking skills provide an important foundation for developing children's phonological processing skills and language, which in turn supports reading development similar to that observed in children with typical hearing.

Other studies have examined the role of age at implantation and its effect on reading comprehension in children with CIs (Archbold et al., 2008; Connor & Zwolan, 2004; Johnson & Goswami, 2010). Connor and Zwolan (2004) utilized structural equation modeling (SEM) to examine the influences of multiple sources (i.e., age at implantation, method of communication, vocabulary skills, preoperative residual hearing, and SES) on the reading comprehension skills of 91 children with prelingual deafness who received their implants at varying ages (mean = 6.78 years). Children were divided into two groups—those implanted at 5 years or younger ($n = 40$) and those implanted after 5 years of age ($n = 51$). The Passage Comprehension subtest of the WRMT-R, the Picture Vocabulary test of the Woodcock-Johnson Test of Cognitive Ability, and the Expressive One-Word Picture Vocabulary Test (EOWPVT) were administered to all study participants. Children's most recent evaluation, including the reading evaluation, and pre-implant scores were analyzed. On average, children were 11 years of age and had 4 years of CI experience at the time of their reading assessment. Children's pre-implant vocabulary scores significantly predicted their post-implant vocabulary scores. Children's pre-implant vocabulary scores had an indirect effect on reading comprehension through post-implant vocabulary, which had a direct positive effect on reading. In addition, children who received their implant prior to the age of 5 years tended to have higher post-

implant vocabulary scores than those implanted after the age of 5 years. Hence, children in the early-implant group had better reading comprehension outcomes, compared to those who received their implant after age 5 years.

Study findings also revealed that children in the later-implant group demonstrated a wider achievement gap between their scores and the scores of typically hearing peers than children who were implanted at a younger age. With regard to SES, children from lower SES families had significantly lower reading comprehension scores than did children from middle SES families. Children who used total communication as their primary mode of communication tended to have stronger pre-implant vocabulary scores, yet mode of communication had no direct effect on children's reading comprehension. Overall, those implanted early (i.e., <5 years) had better outcomes than those implanted at a later age (i.e., > 5 years), yet the researchers acknowledged the presence of an achievement gap in both vocabulary and reading comprehension between children with CIs regardless of age of implantation and their typically hearing peers.

Johnson and Goswami (2010) also examined the effect of cochlear implantation on children's development of phonological awareness, vocabulary, and reading skills in children with profound deafness. They too, were interested in whether children's development was confounded by age at implantation. Study participants included 78 children (59 with hearing loss and 19 with typical hearing) between the ages of 5-15 years. The children with CIs were divided equally into two groups: early- implanted (i.e., implanted less than 39 months, n = 21) and later-implanted (i.e., implanted later than 43 months, n= 22). The study had two control groups—16 children with hearing loss using hearing aids and 19 children with typical hearing, matched for reading age, as assessed by

the Neale Analysis of Reading Ability – Revised (NARA-R; Neale, 1997). Study findings showed that age at implantation had a significant effect on rhyme awareness, receptive vocabulary, and reading comprehension in children with CIs; the earlier the better. Reading development (i.e., reading accuracy and reading comprehension) in the children with CI's was significantly associated with phonological awareness, auditory memory skills, and vocabulary development, suggesting a similar developmental pattern to that of children with typical hearing. However, in general, children with hearing loss, whether implanted or using hearing aids, demonstrated poorer performance on expressive vocabulary and phonological awareness, compared to the younger reading-age matched hearing controls.

Overall, studies on reading comprehension have shown that children with CIs frequently read better than their peers with profound deafness without an implant, yet their performance continued to lag behind that of their typically hearing peers. (See reviews, Marschark, Rhoten & Fabich, 2007; Marschark, Sarchet, Rhoten, & Zapan, 2010). Children who received their implant at an early age tended to have improved reading outcomes, compared to those implanted at a later age. Additional factors, such as performance IQ, SES, and onset of hearing loss influenced children's reading comprehension outcomes after cochlear implantation.

Summary and Next Steps: Language and Reading Development

Research in the area of language and literacy in children with CIs has demonstrated the affordances of cochlear implantation in children with profound hearing loss. Studies have examined language and literacy development in children with CIs by comparing outcomes in children with CIs to children with severe to profound hearing loss

without implants, by comparing outcomes in earlier versus later-implanted children, and more recently by comparing outcomes in children with CIs to their typically hearing peers. Research has shown that children with CIs demonstrated improved language and literacy development, compared to their peers with profound deafness without implants. Children's age at implantation had a significant effect on their speech, language, and literacy development (i.e., earlier age at implantation was associated with improved performance). Children (prelingually deafened) who received their implant at a young age (< 3.5 years) were more likely to reach age-appropriate speech and language developmental milestones, compared to those who were later-implanted.

Studies have examined the relationships between speech perception, speech production, phonological processing, vocabulary, oral language, word reading, and reading comprehension. Although different studies have examined different "pieces of the puzzle", taken together, the results suggest that children with CIs follow a similar developmental sequence in learning to read as their typically hearing peers, as proposed by Paul (2010), even though the majority of children with CIs continue to read below grade-level. Developmental lag in children's literacy development may be partially attributed to the fact that the auditory signal provided by the implant is less than optimal, compared to the auditory signal received by children with typical hearing, thus limiting access to the complete phonological representation of words in children with CIs, which in turn affects their development of phonological awareness and their learning to read words. Limited phonological awareness then stands in the way of their vocabulary acquisition; thus children with CIs vary in their word reading and vocabulary development, which in turn, affects their reading comprehension.

Research on language and literacy acquisition in children following cochlear implantation continues to demonstrate significant variation in individual performance. Studies on language and literacy development in children with CIs are complex, and have revealed that multiple moderating factors associated with age at implantation, the child (e.g., cognitive functioning), and the context (e.g., family size or SES) contribute to the affordances of a CI. It is challenging to consider all these confounding factors, as many of these are inter-related and their interactions are not fully understood. Continued research designed to clarify the nature of these interactions is needed if we are to advance the field of pediatric cochlear implantation and improve language and literacy outcomes in children after cochlear implantation. In conclusion, I proposed such a study to further investigate the effect of cochlear implantation on children's language and literacy acquisition in the early elementary years.

Based on a review of the literature on children with typical hearing and children with CIs, I designed the present study to investigate the complex relationship of various predictors (age at implant activation, child, and context-related) associated with language and reading comprehension outcomes in young children after cochlear implantation. In this study, I examine the effect of age at implant activation, parent's support for home literacy development, parental education (proxy for SES), and amount of preoperative residual hearing on children's auditory, speech, language, and reading abilities after cochlear implantation during the early elementary years. Additionally, I investigate how children's present cognitive, auditory, speech, language, and word-reading abilities are directly associated with their reading comprehension abilities post-implant.

I hypothesized that better reading comprehension outcomes will be associated with a younger age at implant activation and greater levels of residual hearing pre-implant. Furthermore, I hypothesized that children of parents with higher educational levels will have greater home support for literacy development, which, in turn, is associated with improved reading comprehension outcomes after cochlear implantation. In regards to children's present auditory, speech, word-reading, or linguistic abilities being predictive of their present reading comprehension abilities, I hypothesized that each of these factors will be highly correlated with reading comprehension, but that children's vocabulary would be the strongest predictor. This hypothesis was partially grounded in my review of the literature on children with CIs, but also from personal experience as a clinical audiologist working with children with CIs. In the clinical setting, I observed children with CIs who could repeat what they heard yet not truly comprehend it, a noted difference between perceiving speech and understanding speech, which affects vocabulary development and ultimately, reading comprehension. The next chapter provides an overview of the study methodology, including study recruitment, participants, data collection, and methods of analyses.

CHAPTER 3

Methods

To examine whether children who receive a cochlear implant develop age-appropriate reading comprehension, along with factors associated with that development, I administered a battery of auditory, linguistic, and reading measures to children with CIs. Additionally, children's primary caregivers completed a questionnaire to provide demographic information and insight into the children's home support for literacy development. In this chapter, I discuss study recruitment and participants, data sources and collection, and statistical methods used to analyze the data.

Sample and Participant Selection

Study participants were from three large pediatric cochlear implant centers—two clinics located in Michigan and one in Ohio. Each clinic director agreed to share the recruitment flier with families they serve who matched the inclusion criteria. Additional recruitment efforts included sending an email with an electronic copy of the recruitment flier to members of several groups of parents and professionals who work with children with hearing loss (i.e., children with CIs): the Michigan Supervisors of Public School Programs for the Hearing Impaired, the Michigan Teacher Consultants of the Hearing Impaired Listserv, Michigan Hands and Voices, and the Michigan AG Bell Association to inform members of the study.

Study inclusion criteria for CI recipients were:

- Ages 7.0 to 11.0 years at time of the study evaluation
- Prelingually deafened (i.e., deaf from birth or acquired deafness before the age of 2)
- No clinical concern regarding cognitive abilities
- Unilateral or bilateral CI user
- Initial CI received prior to age 5
- Normal cochlear anatomy; full insertion of implant array; if post-meningitic, no signs of ossification in the ear that was implanted per medical records
- Minimum of one year of consistent CI device use
- Native English-speaking family (or, if bilingual, families who commit to educating their child in English-speaking schools), and
- Oral primary mode of communication

Thirty-three children with CIs and their primary caregivers consented to participate in this study. Two of these children were excluded from the study, one for not meeting the oral primary mode of communication criterion, and the other for having less than one year of consistent CI device use as a result of recent explant/re-implant surgery. Thus, the final study sample consisted of 31 children with CIs, 15 males and 16 females.

Descriptive statistics for participants are presented in Table 1.

Twenty-seven of the 31 participants were clinically managed at the University of Michigan's Cochlear Implant program. Based on the clinic's database, this constituted over half of the children who received follow-up care at the clinic who met study

inclusion criteria and who were contacted to participate in the study. Statistical analyses (i.e., χ^2 and ANOVA) were conducted to investigate potential sample bias between the 27 children whose families volunteered to participate and the remaining 25 children who were eligible but did not participate. Reasons provided for not participating included transferred care or moved out of state (3), travel/distance issues (5), and for remaining families (17), no response was obtained after three attempts to contact them regarding study participation. Using information gathered from the clinic's database, I examined differences between the two groups with regards to their gender, etiology of hearing loss, first ear implanted, device used, SES, age at implant activation, and most recent performance on the Peabody Picture Vocabulary Test, Fourth Edition (PPVT-4; Dunn & Dunn, 2007). There were no significant differences noted between the two groups except for chronological age at the time of the most recent PPVT assessment ($F(1, 50) = 11.50$, $p = .001$). Children participating in the study were slightly older at the time of the PPVT evaluation, with a mean age of 8.7 years of age compared to 7.3 years of age for non-participants; however, there was no statistical difference noted for children's actual performance on the PPVT (mean standard scores of 88 and 83, respectively). Thus, there is no reason to believe that the current sample represents a biased subset of the broader clinic sample.

Table 1. *Demographics and Hearing History of Participants*
(*N=31*)

Characteristics	<i>n</i>	%	<i>M (SD)</i>	Range
Gender				
Female	16	51.6		
Male	15	48.4		
Race				
African American	2	6.5		
Caucasian	26	83.9		
Other	3	9.7		
Chronological age at time of evaluation (years)			8.7 (1.06)	7.1 - 11.0
Length of CI use at time of evaluation (years)			6.8 (1.31)	2.9 - 9.0
Etiology of hearing loss				
Auditory neuropathy or dysynchrony	4	12.9		
Familial or genetic	8	25.8		
Meningitis	3	9.7		
Unknown	16	51.6		
Unaided preoperative pure-tone average (dB HL)				
Right ear			103 (13.55)	74 - 119
Left ear			104 (13.79)	75 - 119
CI pure-tone average (dB HL)			21 (2.98)	15.0 - 27.5
Age at activation of first CI (years)			1.9 (.94)	1.0 - 4.5
First ear implanted				
Left	8	25.8		
Right	23	74.2		
Cochlear implant device manufacturer –first CI				
Advanced Bionics	4	12.9		
Cochlear Corporation	27	87.1		
Bilateral implants	12	38.7		
Age at activation of second CI (years)			6.1 (1.59)	3.6 - 8.7
Primary caregiver’s education level (proxy SES)^a				
Graduated high school (1)	1	3.2	3.6 (1.28)	
Some college including technical training (2)	7	22.6		
Graduated two-year college (3)	6	19.4		
Graduated four-year college (4)	6	19.4		
Graduate School (5)	11	35.5		

Note. ^aIndicates the highest level of education attained by a parent or primary caregiver in the home

The average age at evaluation for children participating in the study was 8.7 years, with an average hearing age (i.e., years of CI experience) of 6.8 years. The majority of participants (52%) presented with a hearing loss of unknown etiology; other etiologies included auditory neuropathy or dysynchrony, familial or genetic disposition (e.g., Waardenburg Syndrome, Usher Syndrome, and Connexin 26), and meningitis. Preoperatively, children presented with bilateral severe to profound sensorineural hearing loss with residual hearing² between 70 and 120 dB HL ($M = 100$, $SD = 14.82$). Postoperatively, the average CI or aided four-frequency pure-tone average (PTA) was 21dB HL.

The average age at implant activation for the first CI was 1.9 years ($SD = .94$), with an age range of 1.0 to 4.5 years. The majority of participants (74%) reported receiving their initial CI in the right ear. Twelve of the study participants (39%) underwent surgery for a sequential bilateral implant. The average age at activation of the second implant was 6.1 years ($SD = 1.59$), with an age range of 3.6 to 8.7 years. Of the 31 participants, 4 children (13%) had an Advanced Bionics device, and 27 children (87%) had a Cochlear Corporation (Nucleus) device. All children in the study demonstrated normal or slightly above normal cognitive abilities, as measured by their performance on the Wechsler Abbreviated Scale of Intelligence (WASI; Psychological Corporation, 1999) non-verbal subtests ($M = 107$, $SD = 12.78$).

² The amount of residual hearing preoperatively refers to the calculated four frequency pure-tone average (PTA) at 500Hz, 1 KHz, 2 KHz, and 4 KHz using the lowest threshold level obtained in either the right or left ear. If no response at the limits of the audiometer was noted on the child's preoperative audiogram, +5dB over the limit of the audiometer was used in the PTA calculation (i.e., $110 + 5 = 115$ dB HL at 500Hz and $115 + 5 = 120$ dB HL at 1-4 KHz).

With regards to children's educational placement, the majority of children (77%) were fully mainstreamed in a general education classroom; 7 of the children (23%) were partially-mainstreamed, attending classes in both the general education and resource room settings. All but 5 of the children received their primary reading instruction in the general education classroom. Per parent report, 29 out of the 31 children received additional support services through an Individualized Educational Plan (IEP). For the remaining two children, one received educational supports through a 504 Plan, while the other child received no additional educational services. The educational support personnel identified as providing additional services included a teacher consultant for the hearing impaired (74%), speech pathologist (65%), educational audiologist (48%), and reading interventionist (19%). The most frequently reported educational accommodations were children's use of a personal or soundfield FM system (90%) in conjunction with their CI and preferential seating in the classroom (61%).

Children's educational information was gathered from the parental questionnaire. There were a total of 31 primary caregivers (27 females, 4 males) who completed the parental questionnaire. Racial background of the adult respondents was 91% Caucasian, 3% African American, 3% Asian, and 3% mixed race. All but eight families had at least one college graduate as a primary caregiver in the home. Of those earning a college degree, 19% attained an Associate's degree, 19% a Bachelor's degree, and 36% a Master's degree or higher. (See Table 1).

To compensate participants for their time and travel, families received \$60 in gift cards— \$50 to a local superstore and \$10 to a toy store. Families also received a written

report of their child's test results, including recommendations to share with school staff and other professionals working with their child.

Study Measures

The following provides an overview of the purpose, administration, and scoring of each measure included in the study. (See Table 2 for a summary of assessments).

Cognitive functioning. To confirm clinical judgment regarding children's cognitive abilities, I administered two subtests, Block Design and the Matrix Reasoning, of the Wechsler Abbreviated Scale of Intelligence (WASI; Psychological Corporation, 1999). The WASI is a norm-referenced brief measure of intelligence that can be used with individuals ages 6 through 89 years. The Block Design subtest consists of a series of modeled or two-dimensional geometric patterns which the child must replicate using blocks. This is a timed-test designed to assess the child's visual-spatial organization and nonverbal reasoning. The Matrix Reasoning subtest consists of a series of incomplete two-dimensional patterns which the child must complete by identifying the correct response from five possible choices. This subtest also assesses the child's visual-spatial organization and nonverbal reasoning. When combined, the Matrix Reasoning and Block Design subtests create the Performance Scale and yield the child's Performance (Nonverbal) Intelligence Quotient (PIQ). The reported reliability coefficients for children for the PIQ scales range from .92-.95 (Psychological Corporation, 1999). The construct validity or the extent to which the WASI measures the theoretical construct of PIQ is supported by the intercorrelations of the WASI subtests with the Wechsler Intelligence Scale for Children (WISC-III; Wechsler, 1991). The PIQ intercorrelation coefficient was .87 between the WASI and WISC-III, demonstrating good construct

validity. All 31 participants met the PIQ criteria (no more than one standard deviation below the mean, i.e., PIQ of 85 or above), with a mean PIQ of 107 (*SD* 12.78, Range 89-133).

To assess children's working memory, I included two subtests, Numbers Reversed and Auditory Working Memory, from the Woodcock Johnson III- Normative Update (WJIII-NU) Tests of Cognitive Abilities (Mather & Woodcock, 2001). When combined, these subtests form the Working Memory cluster, with a reported median reliability of .90 in children ages 5 to 19. The Numbers Reversed subtest is designed to measure the child's auditory memory span. For this subtest, the examiner asks the child to repeat in reverse order a series of numbers presented orally (e.g., the examiner says, "8-3-2", and the child responds, "2-3-8"). The Auditory Working Memory subtest also measures the child's auditory memory span. For this measure, the examiner asks the child to listen to a series that contains both numbers and objects. The child has to reorder the information, then repeat the objects heard in sequential order, followed by the numbers in sequential order (e.g., the examiner says, "3-apple-2-cow", and the child responds, "apple-cow-3-2"). This task becomes more challenging as the sequence of numbers and/or words presented in a series increases with subsequent test items. For these two subtests, age-referenced standard scores were used with a norm population mean of 100 and standard deviation of 15.

I administered the cognitive assessments using live-voice presentation with children facing me so auditory and visual cues (i.e., the opportunity for lip reading) were available to all participants. For the Numbers Reversed and Auditory Memory subtests, I

used a digital audio-recorder to capture children's responses and later used these recordings to verify correct response scoring.

Speech perception. I included three measures in the test battery designed to assess children's speech perception abilities; two closed-set measures (i.e., limited set of response possibilities) and one open-set measure (i.e., unlimited set of response possibilities). Closed-set measures are useful when testing speech perception abilities in children with limited vocabulary or poor articulation, while open-set measures tend to be more representative of children's performance in everyday listening situations.

The first closed-set measure, the Minimal Pairs Test (Robbins, Renshaw, Miyamoto, Osberger, & Pope, 1988), was designed to assess children's ability to perceive a single phoneme (speech sound) difference between a pair of words using audition alone. This test consists of 20 pairs of pictured words, with each pair differing by consonant voice (e.g., pat/bat), consonant manner (e.g., shoe/two), consonant place (e.g., pea/key), vowel place (e.g., big/bug), or vowel height (e.g., pea/paw). Each of the pictured words is targeted twice during administration of the test, for a total of 80 test items. The examiner says the target word at a normal conversation level, without visual cues, and the child must point to the appropriate picture associated with the word spoken. For this assessment, I used a hand-held screen, covered with a dark, mesh loudspeaker fabric to prevent children from accessing lip-reading cues during presentation of the target word. I recorded children's scores as percent of words correct by type (e.g., consonant place, consonant manner) as well as total percent of words correct.

The second closed-set measure in the test battery was the Pediatric Speech Intelligibility test (PSI; Jerger & Jerger, 1984), which I administered both in quiet and in

competing noise conditions. The PSI is a picture-pointing task designed to assess the children's ability to recognize and match a spoken sentence with one of five picture choices using audition only (e.g., "A bear is combing his hair"; "A bear is brushing his teeth"). Each of the 5 sentences is presented twice, for a total of 10 items per condition. The PSI consists of two sentence-response cards. For this study, I used the Response Card A and presented the sentences via CD recording in quiet (60 dB SPL) and in noise at a +10 signal-to-noise ratio (SNR) (i.e., target sentence presentation level of 60dB SPL and competing sentence presentation level of 50dB SPL). I recorded the children's scores as percent of sentences correct for both the quiet and competing noise conditions.

For the open-set speech recognition measure, I used List 1 from the Lexical Neighborhood Test (LNT; Kirk, Pisoni, & Osberger, 1995). The LNT is a 50- word list, speech perception measure designed to assess the child's ability to recognize and repeat single-syllable words presented via CD recording using listening alone. The test includes vocabulary familiar to young children. Each 50-word list is comprised of 25 "easy" words and 25 "hard" words. What differentiates the two word groupings is the word frequency in the language and lexical density (i.e., the number of phonemically similar words or neighbors). The easy word list consists of high-frequency, low-density words (e.g., orange; girl), while hard-word list consists of low-frequency words with many lexical neighbors (e.g., meat; bone).

For the recorded speech perception measures (i.e., PSI and LNT), I presented the stimuli to participants via a compact disc player routed through a calibrated audiometer (ANSI S3.6-1996) at a presentation level of 60dB HL. Participants faced either the right or left loudspeaker in the sound-treated booth, whichever was associated with their

implanted ear, at a distance of approximately 3 feet from the loudspeaker. The target stimuli were delivered at 0° azimuth with the competing noise stimuli at 90° directed to the child's non-implanted ear or second implanted ear in the case of bilateral CI users (Eisenberg et al., 2006).

Phonological awareness and word recognition. To assess children's phonological awareness abilities, I included the Sound Awareness subtest from the Woodcock Johnson III- Normative Update (WJIII-NU) Tests of Achievement (Mather & Woodcock, 2001). Phonological awareness is a listening skill that includes the ability to distinguish units of speech, such as rhymes, syllables in words, and individual speech sounds within syllables. The Sound Awareness subtest consists of four measures: Rhyming, Deletion, Substitution, and Reversal. The Rhyming measure requires the child to provide a word that rhymes with the stimulus that is presented orally (e.g., the examiner says, "What rhymes with 'no'?" and the child says, "Go."). The Deletion measure requires the child to remove part of a word to make a new word (e.g., the examiner says, "Say 'fireman' without 'fire'," and the child responds, "Man." Or the examiner says, "Say 'swimmer' without the /er/," and the child responds, "Swim."). The Substitution measure requires the child to substitute a part of a word to create a new word (e.g., the examiner says, "Change the /m/ in 'man' to a /f/," and the child responds, "Fan."). The Reversal subtest requires the child to reverse the letter sounds of a word to create a new word (e.g., pot - /p/ /o/ /t/ reversed to /t/ /o/ /p/ - top). The Sound Awareness subtest has a reported median reliability of .81 in the age 5-19 range (Mather & Woodcock, 2001).

To examine children's word recognition abilities, I administered the Letter-Word Identification subtest and the Word Attack subtest from the WJIII-NU Tests of Achievement (Mather & Woodcock, 2001). The Letter-Word Identification subtest begins by having the child identify letter names and then requires the child to pronounce printed words. This task increases in difficulty, as the words presented in subsequent lists appear less frequently in written English. The Word Attack subtest is designed to measure children's ability to decode and pronounce nonsense words in print. The reported median reliabilities for the Letter-Word Identification and Word Attack subtests are .91 and .87, respectively, in the age 5-19 range (Mather & Woodcock, 2001).

Because children with hearing loss may present with articulation errors (i.e., limited speech intelligibility), I used a digital audio-recorder to capture participants' responses on these measures. The audio recordings were later used to verify correct response scoring. In keeping with the WJIII Tests of Achievement scoring protocol (Mather & Woodcock, 2001), children were not penalized for mispronunciations resulting from articulation errors. After verifying proper scoring, I then calculated children's raw scores (numbers correct) for each subtest to derive age-referenced standard scores with a norm population mean of 100 and standard deviation of 15.

Oral language. To assess children's receptive vocabulary, I administered the Peabody Picture Vocabulary Test, Fourth Edition (PPVT-4; Dunn & Dunn, 2007), Form A. The PPVT-4 is a test of one-word receptive vocabulary in which the examiner provides a label and the child must point to, or say the number of, the picture that best represents the word spoken. The PPVT-4 has a reported median reliability between .93-.96 in the age 7-11 range (Dunn & Dunn, 2007).

To assess children's expressive vocabulary, I administered the Picture Vocabulary subtest of the WJIII-NU Tests of Achievement (Mather & Woodcock, 2001). This subtest is designed to measure the child's expressive word knowledge at the single-word level by having the child name pictured objects (e.g., the child is shown a picture of an ear of corn and must name the object as "corn"). The Picture Vocabulary subtest has a reported median reliability of .77 in the age 5-19 range (Mather & Woodcock, 2001).

To measure children's listening comprehension abilities, I used the Understanding Directions subtest of the Woodcock Johnson III-NU Tests of Achievement (Mather & Woodcock, 2001). This subtest is designed to assess the child's ability to comprehend spoken information, by pointing to various objects in a picture relying on audition only. The information increases in linguistic complexity with each picture presented (e.g., "Point to the dog then the bear", "Point to the balloons or the birthday cake, but after you point to the bird that's not flying"). The Understanding Directions subtest has a median reliability of .77 in the age 5-19 range (Mather & Woodcock, 2001). When administering the Understanding Directions subtest, I presented the test stimuli at the child's most comfortable listening level using a digital recording via an Apple Ipod® connected to a JBL On Stage Micro II Portable speaker. The portable speaker was located in front of the child— next to the WJIII Tests of Achievement easel on the examiner's table.

I administered the expressive and receptive vocabulary measures using live-voice, with children facing me, so auditory and visual cues (i.e., the opportunity for lip reading) were available to all participants. For each of the oral language measures, I calculated children's raw scores to derive age-referenced standard scores with a norm population mean of 100 and standard deviation of 15.

Reading comprehension. I administered the Passage Comprehension subtest of the Woodcock Johnson III-NU Tests of Achievement (Mather & Woodcock, 2001). This subtest is designed to measure reading comprehension by requiring the child to read a series of short passages with one missing word and provide a word that makes sense in the context of the passage (e.g., “The duck is swimming in the ____.”). The test items become subsequently more difficult by eliminating pictorial cues, and by increased passage length and linguistic complexity. The Passage Comprehension subtest has a reported median reliability of .83 in the age 5-19 range (Mather & Woodcock, 2001). As with the other WJIII-NU subtests, I calculated children’s raw scores to derive age-referenced standard scores with a norm population mean of 100 and standard deviation of 15.

Table 2. *Measures of Performance*

Variable	Assessment	Presentation
Cognitive Functioning - Performance Intelligence	Matrix Reasoning and Block Design subtests of the WASI	Live-voice, Block Design timed
Cognitive Functioning - Working Memory	Numbers Reversed and Auditory Working Memory subtests of the WJIII-NU Tests of Cognitive Abilities	Live-voice
Speech Perception	Minimal Pairs Test	Live-voice
	Pediatric Speech Intelligibility (PSI) Test in quiet and noise (+10 SNR)	Recorded (60dBSPL)
	Lexical Neighborhood Test (LNT)	Recorded (60dBSPL)
Phonological Awareness	Sound Awareness Composite-Rhyming, Deletion, Substitution, and Reversal subtests of the WJIII-NU Tests of Achievement	Live-voice
Word Recognition	Letter-Word Identification and Word Attack subtest of the WJIII- NU Tests of Achievement	Live-voice
Receptive Vocabulary	Peabody Picture Vocabulary Test-4 (PPVT-4)	Live-voice
Expressive Vocabulary	Picture Vocabulary subtest of WJIII-NU Tests of Achievement	Live-voice
Listening Comprehension	Understanding Directions subtest of the WJIII-NU Tests of Achievement	Recorded ^a
Reading Comprehension	Passage Comprehension subtest of WJIII-NU Tests of Achievement	Live-voice

Note. WASI = Wechsler Abbreviated Scale of Intelligence, WJIII-NU = Woodcock Johnson III Normative Update

^a Presentation level was set at children's most comfortable listening level.

Speech processor function and mapping. Prior to administering any assessments, I conducted a listening check of children's speech processors by coupling the processor to a set of monitor earphones³. In one case, distortion of the microphone was noted and resolved by replacing the child's speech processor's microphone cover. In addition, to verify children were perceiving sounds across the speech spectrum with their current mapping, I conducted the Ling 6 Sound Check (Ling, 2002) at the beginning of each evaluation session. The Ling 6 Sound test is a listening check designed to quickly assess the child's access to sound across the speech spectrum. The child is seated approximately 3 feet in front of the examiner and asked to repeat the sound heard (/m/, /ah/, /ee/, /oo/, /sh/, /s/) using listening alone. To prevent the child from accessing lip reading cues, I used a hand-held screen, covered with a dark mesh speaker fabric and covered my mouth before randomly presented each speech sound twice. All study participants were able to identify and repeat the six Ling sounds with 100% accuracy.

As part of the test battery, I conducted aided sound-field testing using narrow-band noise at octave frequencies of 250-4000Hz to verify sound awareness across the frequency range with the child's speech processor and current mapping. The mean CI pure-tone average was 21 dB HL (Range, 17-28 dB HL). No concerns were noted regarding speech processor functioning or children's access to sound across the speech spectrum with current CI mapping.

Parental questionnaire: Home support for literacy development. The purpose of this questionnaire was to gather child and family demographics along with information

³I conducted a listening check on the 27 children using a Cochlear (Nucleus) speech processor due to access to the appropriate monitoring equipment.

about the primary caregivers' educational background (proxy for socioeconomic status [SES]), and home support for literacy development. The questionnaire consisted of 49 items and took approximately 15 minutes for the child's caregiver to complete (see Appendix A). I adapted interview questions from a parental questionnaire developed by Dickinson and DeTemple (1998) to ascertain home support for preschooler's literacy development. The questionnaire also included items designed to gather information about the child's educational placement (e.g., grade, primary classroom setting), additional support services received (e.g., speech therapy, reading intervention) and educational accommodations (e.g., FM use, preferential seating, notetaker).

Data Collection

Children and their primary caregivers participated in a one-time test session during June through September 2011 at one of two study locations; an audiology clinic located in southeast Michigan or one in southwest Michigan. Taking into consideration travel time and distance, participating families were able to choose their preferred test location. Each test session lasted between 2 ½ to 3 hours. At the beginning of the evaluation, I reviewed the parental consent, child assent, and release of medical information forms with each family, as required by the University of Michigan's Institutional Review Board (IRB). Participants and their primary caregivers had the opportunity to ask questions related to the study and required documentation. Once consent and assent were obtained, I provided the child's primary caregiver with a paper copy of the parental questionnaire to complete while I began evaluating their child. I gave child participants the option of having their primary caregiver stay in the testing room with them or watch from an observation room. If the caregiver remained in the

room, s/he was not allowed to interact with the child during the session and sat behind the child so as not to distract the child's attention from the examiner and assessments. I incorporated two 5-minute breaks into the evaluation protocol. Children could discontinue the testing or request additional breaks at any time, as stated in the child study assent documentation. None chose to discontinue.

As is typical in the educational setting, I administered the test battery in the child's best-aided condition: unilateral CI, bilateral CIs, or CI plus contralateral hearing aid⁴. For all standardized measures, I followed administration and scoring protocols as provided by examiner manuals, including the suggested recommendations when testing children who are hard of hearing. Recommended accommodations include testing in a quiet room with few visual distractions and administering audio-recorded tests orally, for subtests of the Woodcock-Johnson III Tests of Achievement and Tests of Cognitive Abilities Normative Update (WJ III-NU)⁵. For the various WJIII-NU subtest measures, I used the Compuscore and Profiles Program Version 3.1 (Schranck & Woodcock, 2008) to convert children's raw scores into age-referenced standard scores.

After verifying children's equipment settings and functioning, I proceeded with administration of the WASI to confirm typical non-verbal intelligence. Next, I administered the remaining measures in the following fixed order: PPVT-4, Letter-Word Identification, Understanding Directions, Passage Comprehension, Word Attack, Picture Vocabulary, Sound Awareness Composite subtests, Numbers Reversed, Auditory

⁴ Two out of the 31 children used a contralateral hearing aid in conjunction with their CI. Testing was conducted with the children wearing both their CI and hearing aid except for speech perception and soundfield testing which was assessed in the CI only condition.

⁵ Except for the Understanding Directions subtest of WJIII-NU Tests of Achievement, which was administered via audio-recording to measure children's listening comprehension using audition only.

Working Memory, Minimal Pairs, soundfield audiogram, PSI, and LNT.⁶ Administration of the WJIII- NU Tests of Achievement subtests followed the order of presentation in the WJIII test books (i.e., Letter- Word Identification is subtest #1, Understanding Directions is subtest #4, Passage Comprehension is subset #9).

At the completion of the evaluation session, children received their gift cards and certificate of participation. I then reviewed the parental questionnaire with the child's primary caregiver to address any questions as well as to verify that s/he had provided a response for each item on the questionnaire. I informed the caregiver that s/he would receive a copy of the child's evaluation report. Furthermore, I provided them with a copy of the IRB consent that included my contact information for future reference.

Statistical Analyses

I completed several sets of analyses. Using SPSS 19.0 statistical software, I conducted descriptive analyses to provide means and standard deviations of participant demographics and outcome measures. I used principal component analysis to analyze the survey data to create a latent construct for home support of literacy development (see below). As a second step, I included the home support scale in a sequence of path analyses examining the relationships among various child and contextual variables with language and literacy outcomes. As a last integrative step, I examined the results from the path analyses using structural equation modeling (SEM) via MPlus 6.11 statistical software (Muthen & Muthen, 2011). The use of SEM allowed me to integrate path analyses into one statistical model, which could be tested for overall model fit. By using

⁶ For five of the 7 and 8 year olds in the study sample, I administered the working memory measures (i.e., Numbers Reversed and Auditory Working Memory Subtests) at the end of the test battery to limit test frustration and fatigue, as these tasks appeared more challenging for this particular age group.

SEM, I could simultaneously test direct and indirect effects of multiple factors known to mediate reading comprehension in order to understand the complex interactions of language and literacy learning in children with cochlear implants. Secondly, the use of SEM can account for measurement error when indicators of a construct are measured by more than one variable. For example, in SEM, a latent construct of vocabulary can be created to overcome multicollinearity issues when including a receptive and expressive vocabulary measure in a regression model. Unlike standard multiple regression, SEM allows for the representation of complex theory in a single, integrated model (Kline, 2011).

Prior to conducting the path analyses and SEM, it was necessary to create the variables for SES and home support for literacy development, and to define the final predictors to be included in the models. Socioeconomic status is a strong predictor of children's language and reading development (Hart & Risley, 1995). Debate continues in the literature regarding how best to represent an individual's socioeconomic background (e.g., Entwisle & Astone, 1994). Researchers who study child development have argued that parental educational level is a viable indicator for representing children's SES (e.g., Bradley & Corwyn, 2002; Hauser, 1994). To create the parental education variable, I first re-coded two items from the parental questionnaire related to the highest educational level attained by the respondent and other adult or caregiver in the household using the following scale: 1 = includes some high school, graduated high school, or GED/adult education, 2 = some college including community college and technical training; 3 = graduated two-year college; 4 = graduated four-year college; 5 = graduate school. The

highest degree attained by a parent or primary caregiver in the child's home, regardless of gender, was used to represent the child's SES ($M= 3.6$, $SD=1.28$).

To create a variable representing the frequency of reading in the home, I conducted a principal component analysis of the block question, "In a typical week, how often do you or other family members read the following items to your child?" There were seven reading items in the block (e.g. children's magazines, children's storybooks, newspapers). Results revealed two principal components, with comic books being the only item to load on the second component. The first extracted component had an eigenvalue of 3.016 and explained 43.09% of the total item variance. The six items had an acceptable internal consistency, with Cronbach's alpha = 0.75. A scale score based on these items labeled "reading materials" was used in further analyses.

To create a variable representing home support for literacy development, I conducted an exploratory factor analysis on those items from the parental questionnaire related to home literacy practices. After reverse coding two of the questionnaire items, a higher score on all items indicated higher parental involvement. The following items were included:

- How often do you or other members of the family read with your child in a typical week?
- How many children's books do you own?
- How often do you or other members of the family get books from the library for your child?
- How often do you or other members of the family purchase books from a bookstore or online for your child?

- How often do you discuss stories that your child reads?
- How much do you think you can positively affect your child's reading abilities?

For the final step in creating the home support for literacy construct, I conducted a principal component analysis with the survey questions associated with home literacy practices and the reading materials variable. Three principal components were identified. After inspection of the three-factor solution of the principal component analysis, 37% of the total variance was explained by the first component, with an eigenvalue of 2.59 and Cronbach's alpha of .533. The items' internal reliability was marginal; however, the item loadings were logical and explained over a third of the variance. Thus, a variable was created via SPSS to represent children's home support for literacy development.

After examining the findings from the descriptive analyses, a ceiling effect was noted on both closed-set speech perception measures (i.e., PSI and Minimal Pairs, with means of 99 and 98 percent correct, respectively); therefore, I used children's performance on the Lexical Neighborhood Test (LNT) to represent children's speech perception abilities in all further analyses. The total percent of phonemes score versus total percent of easy or hard phoneme scores on the LNT was used as it had the highest correlation ($r = .37, p = .042$) with children's reading comprehension.

During the final step in preparing the data for path analyses, strong correlations were noted between children's performance on measures of letter-word identification and word attack ($r = .88, p < .001$) and on measures of expressive and receptive vocabulary ($r = .89, p < .001$). Using SPSS, I calculated the variance inflation factors (VIF) to assess issues of multicollinearity. As a result of VIF statistics, I excluded children's

performance on the word attack and expressive vocabulary measures from the final path analyses in order to reduce measurement error related to multicollinearity. However, these independent variables were included in the subsequent SEM analyses as SEM accounts for the covariance among related predictor variables in the integrated model. The next chapter details the results of these analyses, addressing each of the research questions as posed in the present study.

CHAPTER 4

Results

The purpose of this study was to examine whether children who received a cochlear implant (CI) develop age-appropriate reading comprehension, compared to normative data from children with typical hearing, as well as to examine the role of various factors potentially associated with that development. In this chapter, I report the findings from descriptive and inferential analyses, examining age at implant activation, child, and environmental factors and their relation to children's language and literacy development after cochlear implantation. Many of these factors are inter-related, and their interactions are not fully known; therefore, one goal of this study was to clarify the nature of these interactions in order to advance the field of pediatric cochlear implantation and, ultimately, to enhance language and literacy outcomes in children with CIs. I initially examined the direct and indirect effects of the predictor variables on children's reading comprehension using path analyses. Next, I examined the relationship of the predictor variables and their effect on children's reading comprehension using a single, integrated model via structural equation modeling (SEM).

Word Reading and Language Comprehension

Prior to addressing the study research question regarding children's reading comprehension outcomes, it is first necessary to examine children's word reading and language comprehension abilities (as discussed in Chapter 2). Scarborough (2001)

considers these two processes as the key “strands of early literacy development”; skilled reading requires “fluent execution and coordination of word recognition and text comprehension” (p. 98). To become a skilled reader, children must be able not only to recognize the printed word but also to make sense of the strings of words on a page by accessing their background knowledge, vocabulary, understanding of language structures (e.g., syntax), verbal reasoning (e.g., inferencing), and knowledge of literacy (e.g., genres). Therefore, in order to gain a broader understanding of children’s reading comprehension abilities after cochlear implantation, I first report on children’s performance related to the various auditory, language, and word-reading measures included in the test battery.

As shown in Table 3, the children with CIs presented with good open-set speech perception abilities, with a mean score of 92% phoneme recognition of monosyllabic words using audition alone. This finding demonstrates that the children have access to speech sounds via the implant and are able to repeat what they heard with minimal difficulty in a quiet setting. However, adequate speech perception abilities are not necessarily synonymous with listening comprehension. The children with CIs on average performed within the low-average range on listening comprehension ($M = 85$, $SD = 18.6$, Cohen’s $d = .81$) as well as on measures of receptive and expressive vocabulary ($M = 90$, $SD = 19$, Cohen’s $d = .53$; $M = 92$, $SD = 11.1$, Cohen’s $d = .72$, respectively) and working memory ($M = 95$, $SD = 15.4$, Cohen’s $d = .32$). However, the children with CIs demonstrated abilities within the average to above-average range on measures of phonological awareness ($M = 100$, $SD = 22.4$) and word recognition abilities (Letter-Word Identification, $M = 102$, $SD = 15$, Cohen’s $d = .13$; Word Attack, $M = 103$, $SD =$

10.6, Cohen's $d = .28$). As revealed by the effect sizes (i.e., Cohen's d), the children with CIs were performing more than a half a standard deviation (SD) below their age-mates with typical hearing on measures of receptive and expressive vocabulary, and listening comprehension.

Table 3. *Children's Performance on Speech Perception, Language, and Reading Measures (N=31)*

Variable	Min	Max	Mean (SD)	95% CI	Cohen's d
Lexical Neighborhood Test, % Total Phonemes	85	99	92 (4.2)	[90.9, 94]	NA
WJIII-NU Sound Awareness	44	140	100 (22.4)	[91.4, 107.8]	0
WJIII-NU Letter-Word Identification	69	128	102 (15.0)	[96.2, 107.3]	.13
WJIII- NU Word Attack	83	125	103 (10.6)	[98.8, 106.6]	.28
WJIII-NU Working Memory	56	125	95 (15.4)	[89.4, 100.6]	.32
Peabody Picture Vocabulary Test - 4	60	132	90 (19.0)	[82.8, 96.7]	.53
WJIII-NU Picture Vocabulary	74	113	92 (11.1)	[88.2, 96.3]	.72
WJIII-NU Understanding Directions	35	117	85 (18.6)	[78.1, 91.8]	.81
WJIII- NU Passage Comprehension	63	117	91 (14.6)	[85.9, 96.5]	.62

Note. SD = standard deviation, CI = confidence interval, WJIII-NU = Woodcock Johnson III – Normative Update Tests of Achievement or Tests of Cognitive Abilities. All measures except for the Lexical Neighborhood Test (LNT) are reported as age-referenced standard scores with a mean of 100 and a standard deviation of 15.

Cohen's d is defined as the difference between the mean of the children with CIs and mean of norm population (i.e., 100) divided by the standard deviation for the children with CIs.

Reading Comprehension Outcomes in Children with CIs

RQ1: What proportion of children with cochlear implants score in the average range for reading comprehension compared with normative data for children with typical hearing?

Addressing the first research question with regard to reading comprehension outcomes, Table 3 demonstrates that the children with CIs were delayed in comparison to age-referenced standard scores of the norm population ($M = 91$, $SD = 14.6$, Cohen's $d = .62$). On average, the children with CIs were performing more than half a standard deviation (SD) below their age-mates with typical hearing on the WJIII-NU Passage Comprehension subtest. However, 10 out of the 31 children participants (32%) had reading comprehension abilities at or above the mean for their age (i.e., standard score ≥ 100). Taking a more liberal approach, as often reported in the literature (e.g., Geers, 2003; Geers & Hayes, 2010) to include those children who score within 1 SD below the mean of the norm population (i.e., standard score ≥ 85), 21 out of the 31 children in the study (68%) demonstrated reading comprehension abilities within the average range for their age when compared to age-referenced normative data.

In summary, over two-thirds of the children with CIs had reading comprehension abilities within the normal range for their age, although the mean score was at the low-end of average. The children with CIs were performing at or above average in their word recognition abilities (i.e., phonological awareness, decoding, and sight recognition), but were delayed in their oral language comprehension abilities (i.e., vocabulary and listening comprehension). These findings suggest that delays observed in the children's reading comprehension after cochlear implantation were more than likely associated with limitations in areas of language comprehension, which has implications for intervention

in the realm of children's language development in order to foster improved reading comprehension (see Discussion).

Examining the Effects of Auditory, Word Reading, and Linguistic Abilities on Reading Comprehension

RQ2: Which aspects of children's present auditory, word reading, and linguistic abilities are associated with variation in reading comprehension?

The focus of the second research question was to examine factors of children's present auditory, word reading, and linguistic abilities, known to influence reading comprehension in children with typical hearing (e.g., NICHD, 2000; Snow et al., 1998) and determine their association with reading comprehension in children with CIs. First, I examined the correlations among the variables and found a positive correlation between each of the auditory, word reading, and linguistic variables and children's reading comprehension. (See Table 4). The children's receptive vocabulary had the strongest correlation with their reading comprehension ($r = .864, p < .001$), followed by letter-word identification ($r = .847, p < .001$).

Table 4. *Correlations of Measures*
(*N=31*)

Variables	Reading Comp	Speech Perception	PA	Letter- Word Id	Working Memory	Receptive Vocab
Reading Comprehension						
Speech Perception	.368*					
Phonological Awareness (PA)	.774***	.414*				
Letter-Word Identification	.847***	.314~	.812***			
Working Memory	.510**	.215	.673***	.587**		
Receptive Vocabulary	.864***	.460**	.640***	.739***	.327~	
Listening Comprehension	.815***	.509**	.713***	.696***	.427*	.862***

Note. Pearson's Correlations, ~ $p < .10$ * $p < .05$ ** $p < .01$ *** $p < .001$

To determine which variables were key predictors of children's reading comprehension, I conducted a regression analysis as the first step in the path analyses. In the regression model, the dependent variable, reading comprehension, was regressed on children's performance on measures of speech perception, sound awareness, letter-word identification, working memory, receptive vocabulary, and listening comprehension. Table 5 presents the results of this analysis. The children's present auditory, word reading, and linguistic abilities explained 83% of the variance in their present reading comprehension (Adjusted $R^2 = .83$, $F(6, 24) = 24.96$, $p < .001$). The children's reading comprehension outcomes were strongly associated with their receptive vocabulary ($\beta =$

.48, $p = .011$), and marginally associated with their letter-word identification skills ($\beta = .29$, $p = .081$). The children's speech perception abilities, working memory, and listening comprehension abilities were not identified as significant predictors of their reading comprehension in the present model after controlling for vocabulary and letter-word identification.

Because children's listening comprehension had the lowest mean of all the measures (i.e., mean standard score of 85), I carried out additional post-hoc testing. I conducted a regression analysis with listening comprehension as the dependent variable and children's performance on measures of working memory and receptive vocabulary as the independent variables. The children's working memory and vocabulary performance explained 75% of the variance in their listening comprehension abilities (Adjusted $R^2 = .75$, $F(2, 28) = 46.13$, $p < .001$). The children's listening comprehension abilities were strongly associated with their receptive vocabulary ($\beta = .81$, $p < .001$), and marginally associated with their working memory ($\beta = .163$, $p = .102$). This finding suggests that receptive vocabulary was a strong predictor of both children's listening as well as reading comprehension abilities.

Table 5. *Auditory, Word Reading, and Language Measures as Predictors of Children’s Reading Comprehension (N=31)*

Variables	B	SE B	β
Constant	31.339	28.249	
Lexical Neighborhood Test, % Total Phonemes	-.248	.313	-.071
WJIII-NU Sound Awareness	.102	.102	.156
WJIII-NU Letter-Word Identification	.277	.152	.286~
WJIII-NU Working Memory	.048	.101	.050
Peabody Picture Vocabulary Test - 4	.366	.132	.477*
WJIII-NU Understanding Directions	.084	.132	.107

Note. WJIII-NU = Woodcock Johnson III – Normative Update Tests of Achievement or Tests of Cognitive Abilities. Adjusted $R^2 = 0.83$ ($p < .001$)
 ~ $p < .10$ * $p < .05$ ** $p < .01$ *** $p < .001$

Examining Indirect Effects on Reading Comprehension Outcomes

RQ3: How do age at implant activation, child, and context-related factors contribute to individual differences in children’s present auditory, word reading, and linguistic abilities?

The next step in the path analyses was to examine the relationship of age at implant activation, child, and environmental factors to individual variation in children’s present auditory, word reading, and linguistic abilities. This analysis provided insight into possible indirect effects of these factors on reading comprehension as mediated by children’s present auditory, word reading, and linguistic skills. Correlations among these variables are presented in Table 6. Parental education level (proxy for SES) was highly correlated with each measure of the children’s auditory, word reading, and linguistic abilities. Parental education had the strongest association with children’s working memory ($r = .542, p = .002$), followed by speech perception ($r = .477, p = .007$) and receptive vocabulary ($r = .468, p = .008$).

Table 6. *Correlations of Age at Implantation, Child, and Environmental Factors with Auditory, Word Reading, and Language Measures (N=31)*

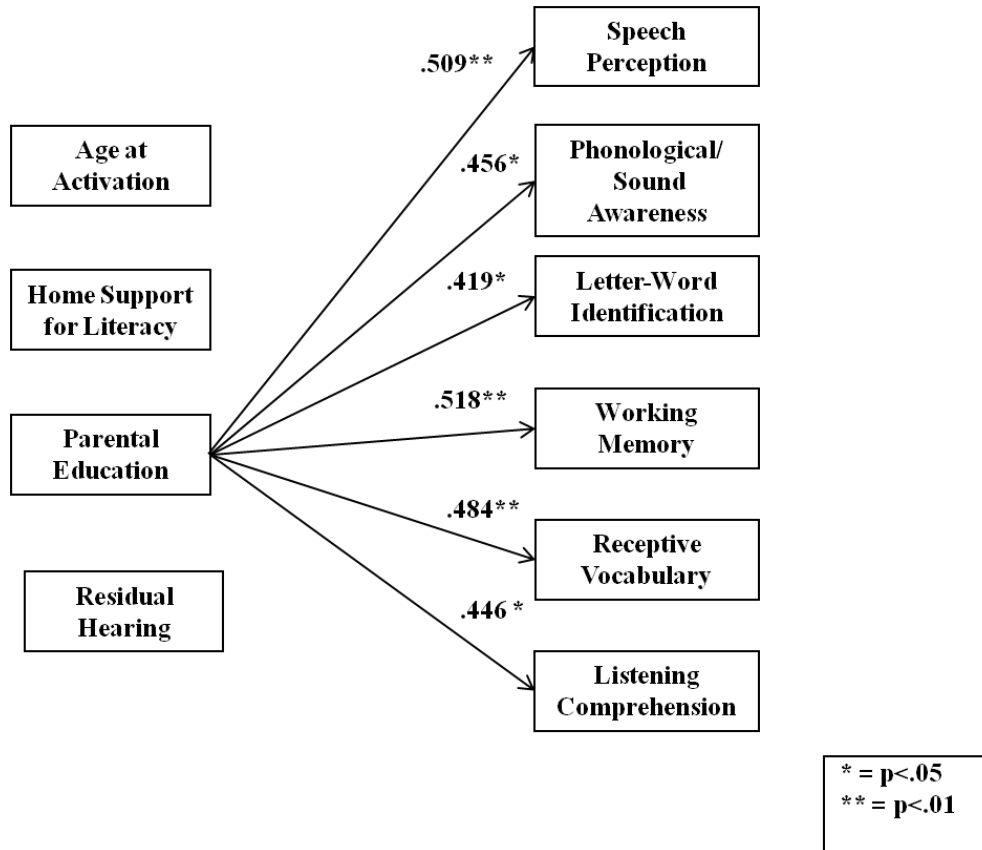
	Speech Perception	PA	Letter-Word Id	Working Memory	Receptive Vocab	Listening Comp	Passage Comp
Male	.042	.046	.030	.066	.318~	.206	.059
Minority	-.023	-.306~	-.206	-.205	.081	-.143	-.110
Age at Activation	.108	.038	-.058	.046	-.112	-.129	-.216
Parental Education	.477**	.447*	.390*	.542**	.468**	.447*	.490**
Residual Hearing	-.143	.025	-.021	.219	.039	.128	-.081

Note. PA = Phonological Awareness
 Pearson's Correlations, ~p<.10 *p<.05 **p<.01 ***p<.001

Next, I conducted a series of six multiple regressions. Each of the six auditory, word reading, and linguistic measures were individually regressed on children's age at implant activation, home support for literacy development, parental education, and residual hearing. For example the first regression model included children's speech perception as the dependent variable and age at implant activation, home support for literacy development, parental education, and residual hearing as the predictor (independent) variables. It should be noted that during exploratory data analyses to account for race and gender effects, I initially included gender (Male, dichotomous variable) and Minority status (dichotomous variable) in the model; however, neither variable explained a significant amount of variance (i.e., critical ratio <1.96) in children's auditory, linguistic, or reading abilities; therefore, these variables were excluded from further analyses.

Figure 1 depicts the significant standardized coefficients (β) from each of the six regression models. Parental education level (proxy for SES) was identified as the primary predictor in children's auditory, word reading, and linguistic abilities. Higher parental education level was associated with higher performance on all measures, with the strongest association noted for children's speech perception ability ($\beta = .51, p = .006$), working memory ($\beta = .52, p = .005$), and receptive vocabulary ($\beta = .48, p = .008$).

Figure 1. *Standardized Beta Coefficients of Multiple Regression Models of Age at Implant Activation, Child, and Environmental Factors as Predictors of Children’s Auditory, Word Reading, and Linguistic Abilities (N=31)*



Examining Combined Effects (Indirect and Direct) on Reading Comprehension Outcomes

RQ4: How do age at implant activation, child, and context-related factors contribute (directly or indirectly) to individual differences in reading comprehension in children with cochlear implants when controlling for present auditory, word reading, and linguistic abilities?

Path analyses were first conducted using results from several multiple linear regressions on the current dataset. Then, I used the analytic method of SEM to examine the covariances between variables from the path analyses to those of the predicted model

to determine goodness of fit of the integrated model. For the SEM analyses, children's scores on the word attack and expressive vocabulary measures were included in the integrated model; unlike multiple regression models, SEM accounts for multicollinearity issues between independent variables.

To examine the direct effect of age at implant activation, child, and environmental factors on reading comprehension controlling for the children's present auditory, word reading, and linguistic abilities, I conducted four, two-step model estimates. Each model had the children's reading comprehension as the dependent variable. Step 1 included each of the auditory, word reading, and linguistic variables, and step 2 included either age at implant activation, home support for literacy, parental education level, or amount of residual hearing pre-operatively as a predictor. The regression models revealing a direct effect are reported in Table 7. Children's age at implant activation (Model 1) and amount of residual hearing pre-implant (Model 2) had a marginal negative direct effect ($\beta = -.15, p = .065$) on children's reading comprehension outcomes; each accounted for 2% of the observed variance in the children's reading comprehension. Parental education level and home support for literacy development had no direct effect on the children's reading comprehension outcomes.

Table 7. *Age at Implant Activation and Residual Hearing as Predictors of Children's Reading Comprehension*
(*N=31*)

Variables	Model	
	1	2
STEP 1:		
Constant	28.107 (26.806)	24.947 (25.650)
Lexical Neighborhood Test, % Total Phonemes	-.041 (.302)	-.110 (.294)
WJIII-NU Sound Awareness	.200 (.098)	.129 (.093)
WJIII-NU Letter-Word Identification	.267~ (.144)	.282~ (.144)
WJIII-NU Working Memory	.056 (.096)	.088 (.098)
Peabody Picture Vocabulary Test - 4	.480** (.125)	.474** (.120)
WJIII-NU Understanding Directions	.050 (.127)	.150 (.124)
STEP 2:		
Age at Implant Activation	-.146~ (1.164)	—
Residual Hearing	—	-.150~ (.077)
Adjusted R ²	.827***	.845***
ΔR^2	.019~	.018~

Note. WJIII-NU = Woodcock Johnson III – Normative Update Tests of Achievement or Tests of Cognitive Standard errors in parenthesis

Model 1: direct effect of age at implant activation on reading comprehension; Model 2: direct effect of residual hearing on reading comprehension.

~ $p < .10$ * $p < .05$ ** $p < .01$ *** $p < .001$

The final step in the path analysis was a two-step regression model, in which, reading comprehension was first regressed on auditory, word reading, and linguistic predictors in step 1, and then step 2 included both the children's age at implant activation and amount of residual hearing pre-operatively. (See Table 8). The final model explained 87% of the total variance in the children's reading comprehension. Results from the final path analysis model continued to demonstrate that the children's letter-word identification had a marginally positive direct effect ($\beta = .275, p = .068$) on their reading comprehension while their receptive vocabulary had a significant positive direct relationship ($\beta = .477, p = .005$). In this final model, age at implant activation and residual hearing were no longer significant (note numbers in parenthesis in Figure 2). However, the R square change from step 1 to step 2 in the regression model was marginally significant ($p = .053$) and explained 3% of the variance in the children's reading comprehension. The decrease in significance level observed on these two variables when included in step 2 of the final model may be explained by their inter-relationship. FDA guidelines stipulate that children implanted under the age of two must present with a profound hearing loss (i.e., poorer residual hearing). Therefore, children with a younger age at implant activation, by default, present with less residual hearing pre-implant.

In summary, the final integrated model (Figure 2) depicts the significant beta coefficients from path analyses conducted to investigate how age at implant activation, child, and context-related factors relate (directly or indirectly) to individual differences in reading comprehension in children with CIs when controlling for their present auditory,

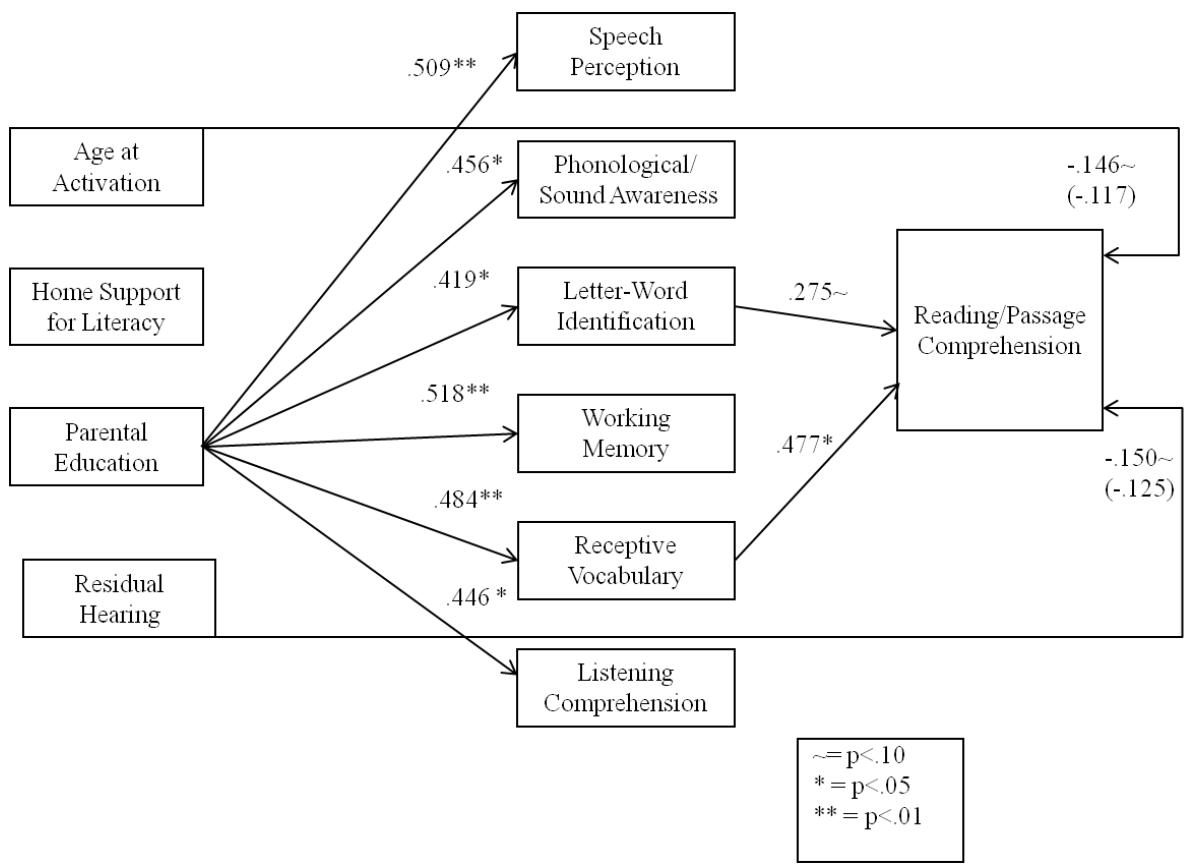
word reading, and linguistic abilities. Parental education level was related to the children's reading comprehension, but in a positive indirect manner mediated through the children's present auditory, word reading, and linguistic abilities. Age at implant activation and amount of residual hearing preoperatively had a marginal negative direct effect on reading comprehension outcomes. The children's receptive vocabulary was the strongest predictor, having a direct effect on reading comprehension outcomes post-implant. The children's letter-word identification skills were also predictive, but only marginally.

Table 8. *Predictors with Direct Effects on Children's Reading Comprehension Outcomes (N=31)*

Variables	B	SE B	β
STEP 1:			
Constant	23.128	24.729	23.128
Lexical Neighborhood Test, % Total Phonemes	-.273	.291	-.079
WJIII-NU Sound Awareness	.109	.091	.169
WJIII-NU Letter-Word Identification	.266	.139	.275~
WJIII-NU Working Memory	.078	.094	.082
Peabody Picture Vocabulary Test - 4	.363	.115	.477**
WJIII-NU Understanding Directions	.072	.122	.093
STEP 2:			
Age at Implant Activation	-1.801	1.093	-.117
Residual Hearing	-.124	.076	-.125
Adjusted R ²			.845***
ΔR^2			.030~

Note. WJIII-NU = Woodcock Johnson III – Normative Update Tests of Achievement or Tests of Cognitive Standard errors in parenthesis
 ~ p < .10 * p < .05 ** p < .01 *** p < .001

Figure 2. Significant Standardized Coefficients of the Final Path Analysis
(N=31)



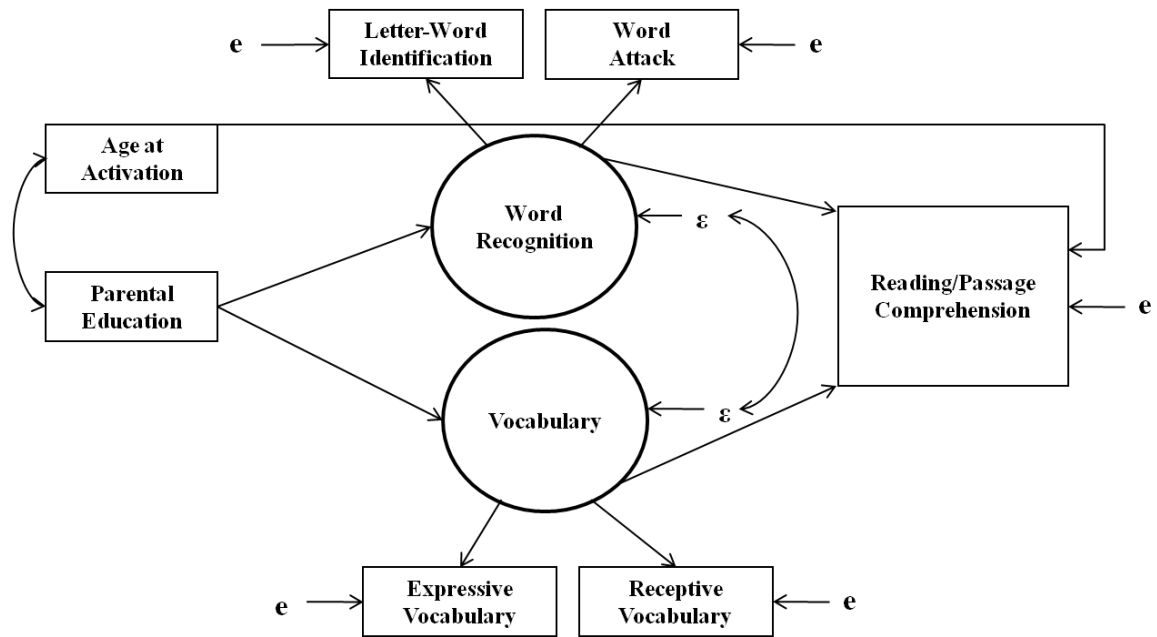
Structural Equation Modeling of Predictors of Reading Comprehension

Next, I analyzed the data using structural equation modeling (SEM). There were two advantages to employing SEM. First, SEM, unlike regression path analysis, allowed me to integrate the path analyses into a single statistical model, which could be tested for overall model fit. Secondly, SEM could account for measurement error if indicators of a construct were measured by more than one variable. For example, in SEM, a latent construct of word recognition could be created to overcome multicollinearity issues when including the children's performance on letter-word identification and word attack in a regression model. Using SEM reduces the risk of having an imprecise estimate of the effect of independent changes in one variable in relation to the dependent variable when the predictor variables are highly correlated.

I conducted SEM in a three-step process. In the initial step, I examined the covariances of variables from the path analyses (See Figure 2) to the covariances of the predicted model to determine goodness of fit of the integrated model. The initial SEM model included all the variables and had twice as many parameters as cases, threatening the accuracy of the parameter estimates in the integrated model. Therefore, the next step included reducing the number of parameters in the model. Only those variables from the dataset which had a significant standardized coefficient (β) of .20 or greater were included in the second version of the model. To further reduce the number of parameters, I created a latent construct for word recognition from the WJIII-NU Tests of Achievement Letter-Word Identification and Word Attack subtests. In addition, I created a latent construct for vocabulary, which combined expressive and receptive vocabulary

measures. In the final step, the integrated model was trimmed further, with a total of 18 free parameters. (See Figure 3).

Figure 3. *Final SEM Model: Path Diagram for Testing the Effects of Age at Implant Activation, Parent Education, Word Recognition, and Vocabulary on Children’s Reading Comprehension*



Similar to findings of from the path analyses, SEM results suggested that age at implant activation, parental education, and the children’s word recognition and vocabulary abilities significantly predicted reading comprehension post-implant. (See Table 9). Several measures of goodness of fit are provided. (See Table 10). The model fails the chi-squared test, revealing that the discrepancy between the observed and model-implied covariances is statistically significant (i.e., $p < .05$). Furthermore, review of the Root Mean Square Error of Approximation (RMSEA) also suggests poor model fit, which is more than likely related to sampling error associated with the small sample size.

Table 9. *SEM Standardized Model Results*
(*N=31*)

Variables	Estimate	SE	CR
Age at Implant Activation to Reading Comp	-.145	.049	-2.924*
Parental Education to Word Recognition	.406	.124	3.287*
Parental Education to Vocabulary	.466	.117	3.968**
Word Recognition to Reading Comp	.434	.098	4.448**
Vocabulary to Reading Comp	.566	.074	7.652**

Note. SE = Standard Error, CR = Critical Ratio
 ~ p < .10 * p < .05 ** p < .01 *** p < .001

Table 10. *Summary of SEM Goodness of Fit*
(*N=31*)

		Chi square (χ^2)	TLI	CFI	RMSEA	SRMR
SEM Trimmed Model	Measure of Fit	23.945	.918	.951	.179	.067
	<i>df</i>	12				
	<i>p</i>	.027				

Note. TLI = Tucker-Lewis fit index, CFI = Comparative fit index, RMSEA = Root Mean Square Error of Approximation, SRMR = Standardized Root Mean Square Residual, df = degrees of freedom, p = p-value

Because of the small sample size, the Standardized Root Mean Residual (SRMR) was also reported. (See Table 10). The SRMR is based on the difference between the observed and predicted correlation residuals. In the present model the SRMR was < .08 suggesting acceptable model fit. However, Kline (2011) suggests, in addition to reporting the SRMR, to inspect the matrix of correlation residuals paying attention to those with absolute values > .10. I inspected the pattern of correlation residuals between

the implied-model and observed-model as an additional indicator of model misfit. (See Tables 11 and 12). Four of the coefficients had absolute values larger $> .10$ (e.g., age at implant activation with vocabulary). Attempts were then made to further optimize the model, but were unsuccessful due to lack of power in the sample. As a final step, I conducted a power analysis based on the final trimmed model incorporating the number of parameters and degrees of freedom to achieve power of $.80$ with an alpha of $.05$. Based on a power table from McCallum et al., 1996 (Table 4, pg 144), I would need to have a minimum of 666 cases to conduct a test of close fit. Considering children with hearing loss, let alone children with CIs, are a low-incidence population, identifying a plausible integrated model via SEM remains challenging.

Table 11. *SEM Correlations of Age at Implant Activation and Parental Education with Vocabulary and Reading Measures (N=31)*

	Letter- Word Id	Word Attack	Receptive Vocab	Expressive Vocab	Age at Implant	Parent Ed	Passage Comp
Letter- Word Id	1.02 1.00	.88	.61	.60	.03	.38	.76
Word Attack	.88	.98 1.00	.60	.58	.03	.37	.74
Receptive Vocab	.74	.52	1.02 1.00	.88	.03	.42	.81
Expressive Vocab	.68	.44	.89	.98 1.00	.03	.41	.79
Age at Implant Activation	-.06	.08	-.11	-.16	1.00 1.00	.08	-.11
Parental Education	.39	.33	.47	.31	.08	1.00 1.00	.41
Reading Comp	.85	.66	.86	.78	-.22	.49	1.00 1.00

Note. The upper diagonal shows the fitted correlations of the implied SEM model. The bottom diagonal represents the observed model correlations.

Table 12. *SEM Fitted Residuals*
(*N* = 31)

	Letter- Word Id	Word Attack	Receptive Vocab	Expressive Vocab	Age at Implant	Parental Ed
Letter-Word Id	-.02					
Word Attack	.00	.02				
Receptive Vocabulary	.13	-.08	-.02			
Expressive Vocabulary	.09	-.14	.00	.02		
Age at Implant Activation	-.09	.05	-.15	-.19	.00	
Parental Education	.01	-.04	.05	-.10	.00	.00
Reading Comp	.09	-.08	.06	-.01	-.11	.08

Summary of Findings

In summary, over two-third of the children (68%) with cochlear implants were performing no more than one standard deviation below the mean (i.e., standard score \geq 85) on a measure of reading comprehension, compared to age-referenced normative data for children with typical hearing. Approximately one-third of the children with cochlear implants were performing at or above average (i.e., standard score \geq 100). Path analyses showed that age at implant activation and amount of residual hearing pre-implant had a marginal negative direct effect on children's reading comprehension. Parental

educational level had an indirect effect on reading outcomes mediated through children's present auditory, word reading, and linguistic abilities, while children's performance on the WJIII-NU Test of Achievement Letter-Word Identification subtest and Peabody Picture Vocabulary Test (PPVT-4) had a direct effect on children's reading comprehension. Structural equation modeling revealed that latent constructs of word recognition and vocabulary were the key predictors of children's reading comprehension, and these were strongly affected by parental education (proxy for SES). Age at implant activation was still negatively associated with children's reading comprehension outcomes post-implant. In conclusion, in children with CIs, proficiency in reading comprehension was associated with a younger age at implant activation, higher parental education level, greater word recognition proficiency, and a broader vocabulary base.

CHAPTER 5

Discussion

An increasing number of children with significant hearing loss are undergoing cochlear implantation during their first few years of life, providing them with greater access to the sound representation of words during the critical years of speech and language development. The need to study this new generation of implant users is imperative in order to better understand and, ultimately, support their language and literacy development after cochlear implantation. The purpose of this study was to establish a deeper understanding of factors associated with individual variations in reading comprehension in children with cochlear implants (CIs). Using path analyses and structural equation modeling (SEM), I examined both direct and indirect effects of various factors (e.g., age at implant activation, SES, receptive vocabulary) on children's reading comprehension outcomes.

In this chapter I first discuss the reading comprehension outcomes of school-aged children with CIs in the present study, compared to age-referenced normative data. Next, I address potential predictors of reading comprehension in these children with CIs as they relate to my original hypotheses and study findings. In addition, I discuss how the results support or extend the literature on children with CIs. Lastly, I address study limitations and suggest directions for future research.

Reading Comprehension Outcomes

Researchers have compared reading comprehension in children with CIs to results from earlier studies reporting reading outcomes in children with severe to profound hearing loss who did not have CIs (e.g., Spencer et al., 1997; Vermeulen et al., 2007). Definitive conclusions from this work are somewhat problematic as the reading measures differed across studies; however, findings suggested that children with CIs demonstrated better reading abilities, compared to their peers without CIs. Considering that children with hearing loss are a low-incidence population, and that an increasing number of children with significant hearing loss are undergoing cochlear implantation, the likelihood of obtaining a control group of children with severe to profound hearing loss without CIs is even more challenging than in years past. As a result, the majority of the recent studies examining reading comprehension after implantation (e.g., Connor & Zwolan, 2004; Geers et al., 2008) have primarily relied on the standard scores from the assessment norm population as a means of comparison. I, too, relied on this comparison in the present study.

In this study, results suggest higher levels of reading comprehension than those reported in previous studies; 21 out of 31 children (68%) in the present study were reading within one standard deviation of the mean for their age (i.e., standard score of 85 or greater) when compared to age-referenced normative data. This finding represents a higher percentage of children with CIs reading within the average range when compared to 52% of children of similar age (8-9 years old) with CIs reported by Geers (2003). This difference could be associated with variation in the audiological and medical management children received pre- and post-implant. Participants in the Geers study

were from across North America and resided in 33 different states and 5 Canadian provinces, while participants in the present study were primarily from one university clinic located in Southeast Michigan. Additionally, this difference could be explained, in part, by the difference in age at implant activation among study participants. In the present study, the mean age at activation was 1.9 years, compared to 3.4 years in the Geers study. Furthermore, the two studies differed in the measures used to assess children's reading comprehension; the Passage Comprehension subtest of the Woodcock Johnson III (WJIII) was used in the present study versus the Reading Comprehension subtest of the Peabody Individual Achievement Test-Revised (PIAT-R; Dunn & Markwardt, 1989). The Passage Comprehension subtest of the WJIII is a modified cloze procedure, in which children are asked to read a series of brief passages of text and report the missing word. The PIAT-R reading comprehension subtest requires children to read a sentence silently, and then select one out of four pictures that best illustrates the sentence (without access to the sentence). Thus, the increase in percent of children with CIs reading within the average range for their age in the present study could be attributed to the age at implant activation or the task difference.

There have been prior studies that have used a modified cloze procedure to measure children's reading comprehension post-implant. Connor and Zwolan (2004) assessed children's reading comprehension post-implant using the Passage Comprehension subtest of the Woodcock Reading Mastery-Test-Revised (WRMT-R; Woodcock, 1987), which is similar to the measure used in the current study. The researchers found that children with CIs ($N = 91$) had a mean standard score of 70, which was 2 *SD* below the mean norm population of children with typical hearing. However,

when examining outcomes based on age at implant activation (i.e., implanted under 5 years and implanted after 5 years), they found that children who were implanted at a younger age had better reading comprehension outcomes ($M = 75$, $SD = 13.5$; $M = 65$, $SD = 11.3$, respectively). In the present study, the mean standard score for children's reading comprehension was 91 ($SD = 14.6$), demonstrating a marked improvement in children's reading outcomes compared to those reported in Connor and Zwolan (2004). Even though the two samples were similar in that the majority of the children received audiological and medical management at the University of Michigan Cochlear Implant Program, the difference in reading comprehension outcomes could be explained by other characteristics of the study samples. In the Connor and Zwolan (2004) study, the average age at implant activation was 6.78 years, average age at reading evaluation was 11 years of age, and the sample included both total and oral communicators. However, in the present study, the average age at implant activation was 1.9 years, average age at reading evaluation was 8.7 years, and the sample included only oral communicators.

Spencer and Olson (2008) also administered the Passage Comprehension subtest of the WRTM-R to measure children's reading comprehension post-implant. Their study sample included 72 prelingually deafened children with an average age at implantation of 3.6 years. Children's reading comprehension skills were assessed on average after 7.5 years of CI experience. Children had a mean standard score of 88 ($SD = 24$), indicating that on average children with CIs were scoring within the low-average range. There appears to be greater variation in children's reading comprehension, as noted by the larger standard deviation than what was found in the present study; however, the mean was similar in that children on average were scoring in the low range of normal.

Although these results are encouraging, the fact remains that children with CIs are performing in the low-average range, compared to their typically hearing peers. I examined the data further to identify those children who were performing at or above age-level (i.e., standard score of 100 or greater) in the present study. Approximately one-third (32%) of the children with CIs were performing at or above their age-level on reading comprehension when compared to their age-mates in the norm population. The remaining 36% were performing within 1 *SD* below the mean. In the present study, the average chronological age at time of assessment for the children with CIs was 8 years, 9 months, with a mean reading comprehension standard score of 91. Based on WJIII-NU Tests of Achievement normative data, the children with CIs had reading comprehension abilities comparable to children with typical hearing who were 7 years, 9 months of age.

For the children with CIs scoring at the low end of average (i.e., SS of 85), their performance corresponds with that of typically hearing children in the norm population who were 7 years, 4 months of age. Achieving a standard score of 85 (i.e., 1 *SD* below the mean) equates with performance in the 16th percentile. Thus, to conclude that pediatric cochlear implant users should be able to meet ordinary classroom academic expectations without additional support or intervention because they fall within the normal range, I argue, could be detrimental. Reporting that children score “within the normal range” may give professionals and parents working with children with CIs a false sense of children’s competency, especially for those children who score in the low-range of normal (i.e., standard score of 85-90). As a field, it might be beneficial to broaden our thinking on how we report and interpret children’s performance on standardized assessments to ensure that children with CIs receive the necessary supports at home and

school to foster not only children's language and literacy development but also overall academic success.

Additionally, children's reading comprehension post-implant becomes concerning when we consider the fact that participants' mean Performance IQ standard score was 107 (*SD* 12.8), which is considerably above average for their age. Yet, children's mean reading comprehension standard score was 91 (*SD* 14.6), which falls within the low-average range compared to age-referenced normative data. This discrepancy poses an additional need to further understand the complexities of learning to read in children with CIs.

In summary, the results of the study suggest that children with CIs are performing better than their counterparts who use hearing aids (Spencer et al., 1997; Vermulen et al., 2007), and that an increasing proportion of children (relative to the findings from past studies) are obtaining reading comprehension abilities within the low-average range for their age. This is an encouraging trend.

Potential Predictors of Reading Comprehension

Although the outcomes regarding reading comprehension summarized above are relatively encouraging, there were significant individual variations among children with CIs in their performance on the reading comprehension measure. Research examining potential predictors (age at implant activation, child, and context-related) on children's performance after cochlear implantation can lead to a deeper understanding and possible explanation of the individual variance observed in children's performance after cochlear implantation. In the following pages, I discuss potential predictors associated with reading comprehension outcomes in children with CIs as they relate to the original

hypotheses and study findings. In addition, I discuss how these findings support or extend prior research on children with CIs.

Age at implant activation. Numerous studies have demonstrated that age at implantation is a key predictor of child's speech production, speech perception, language, and literacy performance post-implant (e.g., Connor & Zwolan, 2004; Nicholas & Geers, 2006; Tomblin et al., 2005). Results suggest that the earlier children with prelingual deafness receive an implant the better their outcomes. This relationship is often attributed to improved access to the sound representation of words during the critical period of speech and language development. In the present study, I used the measure of "age at implant activation," which is calculated by subtracting the children's date of birth from their date of activation. To use the date of surgery for this calculation, as has been the case in some past work, would be misleading as children gain access to auditory percepts only after being fit and programmed with the external speech processor, which typically occurs approximately 3-4 weeks post-operatively, but may vary from clinic to clinic.

Guided by the critical period hypothesis (Lenneberg, 1967) and prior research, I hypothesized that age at implant activation would be a strong (negative) predictor not only of children's reading comprehension but also of their performance on various auditory, word reading, and language measures. Study findings revealed that age at implant activation had a marginally significant negative direct effect ($\beta = -.15, p = .065$) on children's reading comprehension, explaining approximately 2% of the variance. There were no indirect effects of age at implant activation as mediated by children's auditory, word reading, or language performance. The observed marginal negative direct

effect suggests that a younger age at implant activation was associated with higher reading comprehension post-implant.

Given consistent findings in the literature of connections between speech perception, linguistic processes, and reading outcomes, it is surprising that no indirect effects were observed with mediating variables such as speech perception and vocabulary measures. However, the absence of evidence for such mediator pathways could be explained by the relatively young mean age at implant activation and the narrow variation of the present sample ($M = 1.9$ years, $SD = .94$, Range = 1.0 to 4.5 years); the sample was quite homogenous in regards to age at implant activation. With the majority of children in the sample receiving access to sound under the age of 2, this variable is not as strong a predictor in early speech perception and language performance as has been the case in previous studies, where the mean age at implantation was 6.78 years ($SD = 3.06$; Connor & Zwolan, 2004) or 3 years, 5 months (Range = 1 year, 8 months – 5 years, 4 months; Geers, 2003).

In the present study, age at implant activation was marginally significant but consistent with the argument by Marschark et al. (2007), in which, the affordances of cochlear implants in children's reading may result from improvement in auditory perception but could be also be related to other factors such as incidental learning or improved cognitive growth. Perhaps the observed direct effect on reading comprehension is explained by an increase in children's access to world knowledge and overall cognitive development at a relatively young age. Children who receive an implant at an early age have the enhanced ability to engage in auditory experiences that

connect them to the world around them, thereby supporting enhanced cognitive development.

In summary, study findings suggest that a younger age at implant activation is associated with improved reading outcomes. With a mean age at implant activation of 1.9 years, the study sample represents one of the youngest cohorts of children reported in the literature. The fact that two-thirds of these children had reading comprehension within the normal range is promising and hopefully can be maintained as they continue through high school and beyond. With continued support of state-level Early Hearing Detection and Intervention programs, public awareness of cochlear implants, and timely referrals for cochlear implantation, I project that age at implant activation will no longer be considered a variable of interest in future studies measuring the effects of cochlear implants in children with prelingual deafness.

Amount of residual hearing preoperatively. Another factor associated with children's performance after cochlear implantation is children's residual hearing preoperatively (Nicholas & Geers, 2006; Zwolan et al. 2004). Greater residual hearing may be an indicator of improved neural survival of a child's auditory system. Greater access to sound via hearing aids preoperatively allows for stimulation of children's auditory pathways and sound awareness pre-implant. In the present study, I hypothesized that children with better residual hearing prior to implantation would have improved reading comprehension postoperatively. As with (earlier) age at implant activation, I projected that (greater) amount of residual hearing would also be associated with improved performance on the mediating variables, such as speech perception, listening comprehension, and vocabulary.

Contrary to this expectation, the results revealed that the amount of residual hearing preoperatively had a marginal *negative* direct effect on children's reading comprehension ($\beta = -.15, p = .065$). This finding indicates that children with less hearing prior to implantation had better reading comprehension outcomes. I argue that this finding relates to the study sample. Overall, the mean four-frequency pure-tone average (PTA) of participants was 100 dB HL (SD 14.8), indicating that on average children in the sample had minimal residual hearing preoperatively. This is partially confounded by children's mean age at implant activation (1.9 years) and current FDA criteria for pediatric cochlear candidacy. FDA guidelines stipulate that children under the age of two must present with profound hearing loss bilaterally to be considered appropriate candidates for cochlear implantation while children over the age of 24 months have more lenient guidelines; they must have a bilateral severe to profound hearing loss. Thus, children who receive an implant prior to the age of two have minimal residual hearing by default preoperatively. This may explain the observed negative direct effect of residual hearing on reading comprehension outcomes.

This finding raises the question of modifying the current FDA criteria with regards to degree of hearing loss for children implanted under the age of two. In the present study, children implanted under the age of two, who present with a profound hearing loss, are outperforming older children with greater residual hearing (i.e., severe-to-profound hearing loss). Broadening the FDA guidelines for implantation of children under two years of age to include children with a severe-to-profound loss could potentially result in a greater number children with CIs reaching language and literacy outcomes commensurate with their typically hearing peers.

As the age at implant activation decreases, the role of residual hearing in predicting language and literacy outcomes lessens. However, residual hearing remains a variable of interest in studies which include children with CIs who were postlingually deafened. These children had access to sound during the critical period of speech and language development prior to implantation, supporting children's acquisition of phonological awareness and oral language development, thereby influencing children's reading development. Controlling for the amount of residual hearing in a study that contains both pre- and postlingually deafened children with CIs is important when explaining the variance in children's performance outcomes after cochlear implantation.

Parental education level and home support for literacy development. Parental education (proxy for SES) and children's home environment have been well documented as key predictors in children's language and literacy development (e.g., Hart & Risley, 1995; Neuman & Dickinson, 2001). In the present study, parental education (proxy for SES) had no direct effect on children's reading comprehension outcomes. However, parental education level was related to children's reading comprehension, albeit in an indirect manner mediated through children's present auditory, word reading, and linguistic abilities. Over half of the children in the present study (55%) had at least one parent with a college degree residing in the home. Findings showed that higher parental education level was associated with children's improved performance on all of the auditory, word reading, and language measures included in the test battery. The strongest associations were noted with respect to children's speech perception ability, working memory, and receptive vocabulary. Geers et al. (2003) also found that higher SES (in their case, the sum of ratings for parents' income and education) was associated with

improved speech perception, speech production, and language in children with CIs. In their study, over two-thirds of the children (64%) had at least one parent who was a college graduate. Additionally, Geers (2003) identified children's SES status as an important predictor in the development of children's reading skills post-implant; higher SES was associated with higher reading achievement. Similarly, Connor and Zwolan (2004) found that children with CIs from lower SES families had poorer reading comprehension outcomes compared to children from middle SES families. These results regarding the role of SES are consistent with the literature on typically hearing children (Hart & Risley, 1995; Neuman & Dickinson, 2001).

In the present study, I also included a measure of home support for literacy development. Intuitively, one would think that parental education level would be strongly correlated with children's home support for literacy; that is, highly educated parents might be expected to provide greater support in the home to foster children's language and literacy development. However, this was not the case in the current study. This outcome may be related, in part, to how the home support for literacy variable was defined. Children's primary caregivers completed the parental questionnaire, which included items regarding home literacy practices (e.g., In a typical week how often do you read to your child? How many children's books do you own?). Many of the questions used to create this composite were designed for evaluating home support for literacy development in preschoolers (Dickinson & DeTemple, 1998). Thus, in retrospect, the question, "In a typical week, how often do you read to your child?" was likely problematic for the present study, as parents reported that their school-aged children tended to read independently. Furthermore, there was minimal variation

observed in the caregivers' responses to questions designed to capture home support for literacy. For example, one question often associated with home support for early literacy in the literature relates to the number of children's books present in the home. In the study questionnaire, caregivers were asked, "How many children's books do you own?" Caregivers were provided with only three possible responses: a) 1-10, b) 11-25, or c) more than 25 books. All but one primary caregiver responded to owning more than 25 children's books. Perhaps restructuring this question to include a larger range of options as well as additional questions that asked parents to identify specific children's book titles and authors (Senechal, LeFevre, Thomas, & Daley, 1998), may have resulted in a better measure associated with children's home support for literacy development. Thus, flaws in the questionnaire design and issues related to parent self-report may explain the lack of response variation and the lack of an association between parental education and home support for literacy. Perhaps examining the relationship of parent's literacy practices in the home (i.e., the parent as a literacy role model) to school-age children's reading performance may be a more reliable measure (Rashid et al., 2005).

Only a few studies of children with CIs have included an examination of the role of SES or the role of the home environment on children's language and literacy outcomes (e.g., Connor & Zwolan, 2004; Geers, 2002; Niparko et al., 2010; Spencer & Oleson, 2008). Geers (2002) included a questionnaire to estimate the frequency with which parents participated in activities designed to stimulate their children's speech and auditory development in the home. Findings showed that parents participated in activities with greater frequency during the first two years after cochlear implantation and less frequently over time. However, there was no discussion by the researcher as to

whether this finding was associated with children's language and literacy outcomes after cochlear implantation. With all that is known about the role of SES and the home environment on language and literacy development in children with typical hearing, more research is needed to examine how these factors influence the performance in children with CIs.

Word recognition. As discussed earlier, Scarborough (2001) acknowledged two inter-related components of early literacy development, one being children's word recognition abilities (i.e., phonological awareness, decoding, and sight recognition of familiar words). In the current study, children with CIs demonstrated abilities within the average to above-average range on measures of phonological awareness ($M = 100$, $SD = 22.4$) and word recognition abilities (Letter-Word Identification, $M = 102$, $SD = 15$; Word Attack, $M = 103$, $SD = 10.6$). Additionally, path analyses revealed that children's letter-word identification had a marginal, but positive, direct effect on children's reading comprehension outcomes post-implant. These findings suggest that children with early implantation employ their sight recognition or phonological skills in decoding unfamiliar words in print. Hence, it appears that children with CIs have an ample representation of the sound structures of words via the implant to support their phonological awareness, leading to improved phonological processing and decoding, which in turn, fosters children's word recognition abilities and reading comprehension.

James et al. (2008) found that children implanted at a young age (i.e., 2 – 3.5 years) had phonological awareness performance on syllable, rhyme, and phoneme tasks that fell within the standard distribution of reading-matched children with typical hearing. Vermeulen et al. (2007) compared measures of visual word recognition in children with

CIs and instructionally-aged matched peers. The researchers found no difference between the two groups on their visual word recognition skills. Geers (2003) examined children's nonsense and real word recognition after cochlear implantation, and like the present study, observed a positive relationship between children's word reading and reading comprehension post-implant.

Language and vocabulary development. Because CIs can provide children with profound hearing loss with improved access to auditory stimuli, it is presumed that this, in turn, would provide them with greater opportunity to develop oral language skills, including enhanced vocabulary development. In the present study, children's vocabulary performance had a strong positive direct effect on children's reading comprehension outcomes post-implant. In addition, parent education had a positive indirect effect on children's reading comprehension mediated through children's receptive vocabulary. Similar to the present study, Geers (2003) found that children's speech perception scores did not contribute independently to children's reading competence; however, children's language skills explained a good portion of the variance in children's reading outcomes. Geers argued that the auditory perception achieved with a cochlear implant may not promote learning to read if children are not competent in the English language. Spencer et al. (2003) also found a strong correlation between children's language performance and reading performance.

Other studies (e.g., Connor & Zwolan, 2004; Hayes et al. 2009; Johnson & Goswami, 2010; Niparko et al., 2010) have examined the relation of age at implantation to children's language abilities. Similar to the present study, Connor and Zwolan (2004) identified a direct, positive, effect of children's post-implant vocabulary on their reading

comprehension. In addition, they found that age at implant activation had a negative indirect effect on children's reading outcomes mediated by children's post-implant vocabulary (i.e., those with later age at implant activation had poorer vocabulary which, in turn, resulted in poor reading comprehension). Hayes et al. (2009) revealed that on average children with CIs had lower receptive vocabulary skills than their typically hearing peers; however, those children who were implanted at a younger age had steeper growth rates than children who were later implanted.

In a more recent study, Johnson and Goswami (2010) found large discrepancies between children's language age in months and their reading comprehension age in months post-implant, regardless of study group (i.e., early-implant, late-implant, or hearing aid control group). Children in the early-implant group on average demonstrated a delay of 15 months on their reading comprehension, compared to reading-age controls with typical hearing, yet children were lagging 29 months in their receptive vocabulary. This discrepancy observed between language and reading comprehension, however, was more pronounced in children in the later-implanted and hearing aid control groups. Niparko et al. (2010) found that in addition to age at implantation, the greater residual hearing pre-implant, higher ratings of parent-child interactions, and higher SES were associated with greater rates of language comprehension and expression in children after cochlear implantation.

Overall, research has demonstrated that children with CIs remain delayed in their language development, which in turn, affects their reading comprehension. As previously mentioned, Scarborough (2001) refers to language comprehension as one of the inter-related strands necessary for early literacy development. Children need to be

competent in both word recognition and language comprehension in order to become a skilled reader. In the present study, both letter-word identification and children's vocabulary knowledge had a positive direct effect on children's reading comprehension outcomes. However, the strongest predictor of reading comprehension was children's receptive vocabulary. This finding is similar to that of a study by Nation and Snowling (2004) designed to examine predictors of reading comprehension in children with typical hearing. Nation and Snowling's study sample consisted of 72 children with typical hearing, with a mean age at assessment of 8.5 years (similar to the present study). The researchers concluded that both children's word recognition abilities and their vocabulary were significant predictors of their reading comprehension. Children's vocabulary was the stronger predictor, explaining 25% of the variance in reading comprehension, with non-word reading and phonological awareness explaining 20% of the variance. This pattern suggests that children with CIs appear to be developmentally similar to children with typical hearing in regards to reading comprehension, validating the use of mainstreamed literacy models as posed by the Qualitative-Similarity Hypothesis (Paul, 2009; Paul & Lee, 2010).

Additionally, in the present study, age at implant activation and parental education were predictors of language and literacy development in children with CIs. Providing parents, especially those from lower SES background, with strategies for fostering their children's language development may be one way to improve children's reading outcomes after cochlear implantation. Instructional practices designed to foster children's language development may help to prevent later reading difficulties in children with CIs. Both of these implications have been addressed in regards to supporting

reading development in children with typical hearing (e.g., Duke & Carlisle, 2011; NICHD, 2000; Snow et al., 1998).

Limitations

Next, I discuss the limitations of the study. I address limitations associated with the measures used, methods of data collection, and issues related to generalizability of the study findings.

Measures. One limitation of the study relates to the measures used to assess children's speech perception abilities. In the present study, children's speech perception ability had no direct effect on children's reading comprehension outcomes. This negative finding may be related to some unobserved indirect effect, but it may also be simply a result of limited variation in children's speech perception outcomes using the present measures. Three measures designed to assess children's speech perception abilities were included in the test battery—two closed-set tasks (i.e., Minimal Pairs test and the Pediatric Speech Intelligibility test [PSI]), and one open-set task (i.e., Lexical Neighborhood Test [LNT]). Ceiling effects were noted on both closed-set measures, and they were, therefore, removed from data analyses. Additionally, participants had minimal variation in their performance on the LNT measure, with a mean score of 92% phonemes correct (Range, 85 – 99). Furthermore, testing of the LNT was assessed only in a quiet setting, which may overestimate children's speech perception abilities in their daily listening environments (e.g., noisy classroom). Conducting testing in noise, using talker-babble and varying signal-to-noise ratios, may provide a more accurate picture of children's auditory perception abilities. Thus, more sensitive measures may eventually demonstrate that children's speech perception in noise may be a stronger predictor of

children's language and literacy development after implantation than is indicated by the present findings.

Another limitation to consider is that the present study measures may be actually overestimating children's speech perception abilities (in quiet) due to the relationship of children's vocabulary and prior knowledge with the speech perception measure. This becomes apparent on sentence measures designed to assess children's speech perception, where children may hear only part of a word or sentence, yet can complete the task by engaging their vocabulary knowledge. Thus, including measures that assess children's perception of nonsense words or vowel-consonant patterns may provide a better estimate of children's auditory perception post-implant.

As previously mentioned, there were limitations associated with the measure designed to capture children's home support for literacy development. The parental questionnaire included items that may have been more appropriate in gauging home support for literacy development for younger children (i.e., preschoolers) versus the school-aged children in the present sample. Including items in the questionnaire to assess parents' literacy practices may provide a better approximation of children's home support for literacy development in the early elementary years.

Lastly, children's development of language and literacy involves many components (e.g., phonological awareness, fluency, and vocabulary), and these components are inter-related and may vary in their relationship at different stages of learning to read. In the present study, children's auditory, language, word reading, and reading abilities were assessed at one point in time, the early elementary years. The results suggest that children's present phonological awareness ability was not a predictor

of children's reading comprehension in the early elementary years. However, if the study had included children's performance on phonological awareness measured in kindergarten, the data may have revealed a predictive relationship among children's early phonological awareness abilities and children's later reading comprehension (Spencer & Oleson, 2008).

Sample. In the current study, I attempted to control for some of the factors known to influence children's performance after cochlear implantation. For example, the study included only children who were prelingually deafened and who had an oral primary mode of communication. Additionally, 27 out of the 31 participants were clinically managed at the University of Michigan Cochlear Implant Program, which provides weekly or bi-weekly speech and auditory-verbal therapy sessions to children post-implant. Although this feature of the study's design allowed me to avoid potential confounding factors, it limits the generalizability of the study findings to children with similar characteristics. Also, the present study included children with CIs ranging in ages from 7.1 to 11 years; thus caution needs to be used when making generalizations beyond the present study to children of differing age ranges.

Additionally, there are problems associated with estimating standard error considering the small sample size ($N=31$). Therefore, in the present study, the lack of statistical significance of a predictor variable does not necessarily mean a lack of association with children's reading comprehension post-implant. Another limitation of small studies, such as this, is that they can produce false-positive results, or over-estimate the magnitude of a relationship among variables of interest. To overcome these limitations and the fact that children with CIs are a low incidence population, multi-

center studies such as the one reported in Niparko et.al (2010) should be considered to further understand children's language and literacy development after cochlear implantation.

Another limitation associated with the study sample is the fact the comparison group was the age-referenced normative data of the various assessments. Including a control group of typically hearing peers or siblings would provide a better comparison. Additionally, including a comparison group of hard-of-hearing peers might provide greater insight as to whether children with CIs are developing language and literacy skills similarly to other children with functional hearing loss.

Future Studies

The present study is cross-sectional in nature, looking at one point in time in the early elementary years. As children continue through schooling, the process of reading becomes increasingly complex, with continued demands of learning specialized vocabulary and sophisticated syntax. Thus, it is important to conduct longitudinal studies to examine whether the gap in reading comprehension between children with CIs and their peers with typically hearing narrows, remains stable, or widens over time. Geers and colleagues (2010) compared language and literacy outcomes in children who had received an implant prior to 5 years of age at two later time points—in the early elementary years and in the high school years. The researchers found that 66% of the children assessed in the high school years had reading comprehension within or above average for their age (i.e., a standard score of 85 or above). Performance in the high school years was strongly associated with children's performance in the early school years. The majority of children with CIs (72%) maintained their reading levels over time

compared with their hearing peers, indicating that the reading gap was, at least, not widening. Considering the relatively young age at implant activation of children in the present study, one might predict that examining performance over time would reveal a narrowing of the reading gap as a result of improved access to auditory perceptions during the critical period of speech and language development.

With an increasing number of children undergoing bilateral implantation (simultaneous or sequential), research on this population may provide further insight into the affordances of cochlear implants in children with significant hearing loss. In a review of the literature (Murphy & O'Donoghue, 2007), studies in children with bilateral implants have shown improved localization and speech perception in noise compared to children with unilateral CIs. However, the extent to which bilateral CIs foster children's language and literacy development is unclear, as limited research exists on this topic. With the benefits of hearing in noise, one might predict that bilateral implantation would provide children with greater access to incidental learning opportunities, thus supporting language and literacy development. Additionally, binaural stimulation of the auditory cortex may foster improved cognitive development in comparison to children with unilateral CIs, in turn, supporting children's language and literacy acquisition following bilateral implantation. Future studies designed to evaluate the relationship of age at implant activation of the first ear implanted to that of the second ear implanted in children who receive a sequential implant may lead to a deeper understanding of sensitive periods for development (i.e., Does the time between receiving the first and second implant influence children's outcomes, or does the age at implant activation of the first ear play a more influential role in children's performance post-implant?)

Another area that has received minimal attention is the role of children's home environment and parent-child interactions on children's performance outcomes after cochlear implantation (Niparko et. al, 2010). Research on children with typical hearing has demonstrated that children who display reading difficulties early on continue to read poorly throughout their schooling and beyond (Juel, 1988; Scarborough, 2005). Hence, support for early literacy development during the preschool years is imperative. It has been well documented that children's exposure to a language-rich environment in the home prior to schooling is a strong predictor of children's later literacy learning (Neuman & Dickinson, 2001).

In the present study, higher parental educational level (proxy for SES) was associated with improved speech perception, phonological awareness, word recognition, working memory, listening comprehension, and vocabulary in children with CIs, and thus indirectly associated with children's reading comprehension outcomes. Therefore, research on parent-child interactions designed to examine the role of parental education (proxy for SES) on amount, variety, and complexity of adult language, and how this relates to children's language and literacy development, could be insightful.

Additionally, the transactional model of development acknowledges that the relationship of the children and their environment is interdependent and bidirectional (Sameroff, 2009). Unlike the present study, which examined only one direction (i.e., parents influence on children's language and literacy development), studies on parent-child interaction can examine not only the influence of adult language on children language and literacy development, but also how children's language influences the amount, complexity, and variety of language use by caregivers.

It is an exciting time for this field of study, as children with significant hearing loss have greater potential to reach language and literacy development commensurate with their typically hearing peers. However, it is only through continued research designed to examine the effects of bilateral implantation, effects of new advances in technology, effects of contextual factors (e.g., instructional practices, home support for literacy, SES, and educational accommodations) that we can further advance the field of pediatric cochlear implants and gain a deeper understanding of the affordances of cochlear implants and, in turn, fostering children's development after cochlear implantation.

Conclusion

The results of this study suggest that children with prelingual deafness who receive a cochlear implant at an early age have a better prognosis for improved reading comprehension compared to their peers without an implant or those later-implanted. Improved access to the sound representation of words via an implant during the critical period of speech in language development is the underlying premise of improved outcomes in children after cochlear implantation. The present study has shown that children who on average receive their implant under the age of two are attaining adequate speech perception abilities post-implant. However, improved auditory perception is not synonymous with improved comprehension. Marschark et al. (2010) brought this issue to the forefront in their chapter entitled "Will Cochlear Implants Close the Reading Achievement Gap for Deaf Students?" The authors acknowledged the benefits of cochlear implantation in improving outcomes in children with profound deafness, yet if we are to truly understand how best to educate and close the reading achievement gap,

research needs to move beyond focusing on issue of auditory perception and consider issues of language and cognition (e.g., role of incidental learning, metacognition, language interactions) and their association with reading development.

6. Please indicate your child's **primary** mode of communication **at home** (*check one*):

- Oral Mode/Spoken Language
- Total Communication/Spoken and Sign Language
- Visual Mode/Sign Language

7. Please indicate your child's **primary** mode of communication **at school** (*check one*):

- Oral Mode/Spoken Language
- Total Communication/Spoken and Sign Language
- Visual Mode/Sign Language

8. How old was your child when his/her hearing loss was identified:

_____years;_____months

9. How old was your child when he/she was first fit with hearing aids:

- Right ear:** ____year;____months of age
- Left ear:** ____year;____months of age

10. When did your child undergo cochlear implant surgery:

- Right ear:** ____ / ____ / ____
month day year
- Left ear:** ____ / ____ / ____
month day year

11. Where did your child undergo his/her cochlear implant surgery (*check all that apply*):

- Detroit Children's Hospital
- Henry Ford Hospital
- Michigan Ear Institute
- Spectrum Health
- University of Michigan Health System
- Other (*specify*):_____

12. What type of implant(s) does your child have (*check one*):
- Advanced Bionics device
 - Cochlear Corporation– Nucleus device
 - Med-El device
 - I don't know
13. How often does your child have his/her cochlear implant(s) reprogrammed (*check one*):
- At least once a month
 - At least once every three months
 - At least twice a year
 - At least once a year
 - Once every two years
14. On average, how many **hours** a day does your child wear his/her cochlear implant (*check one*):
- 0-4 hours
 - 5-9 hours
 - 10-14 hours
 - More than 14 hours
15. On average, how many days a week does your child wear his/her cochlear implant (*check one*):
- 1 day/week
 - 2 days/week
 - 3 days/week
 - 4 days/week
 - 5 days/week
 - 6 days/week
 - 7 days/week

16. In the past year, has your child received individual speech and/or auditory training therapy **outside of school or the home** (*check one*):

- Yes (*please specify average hours per week*): _____ hrs/wk
- No

If yes, do you or your child's other family member take part in the therapy session (*check one*):

- Yes
- No

17. What type of educational program does your child currently attend (*check one*):

- Fully-mainstreamed in a general education classroom with typical hearing peers
- Partially- mainstreamed – child spends time between general education and resource room/self-contained classroom
- Full-time self –contained classroom for children with hearing impairment or additional needs
- Residential School for the Deaf/Hard of Hearing (e.g., Michigan School for the Deaf)

18. Where does your child receive his/her **primary** reading instruction in school (*check one*):

- General education classroom with typical hearing peers
- Self-contained classroom for children with hearing impairments or additional needs
- Other (*specify*): _____

19. Please identify any additional reading support your child received in the past year either at school or outside of school (*check all that apply*):

- No additional reading support received
- Reading Recovery
- Read 180
- Outside-school services (e.g., Sylvan Learning Center, private tutor)
- Other (*specify*): _____

20. Does your child currently receive education support services through an Individualized Education Plan (IEP) at school (*check one*):

- Yes
- No
- I don't know

If **yes**, how comfortable are you in helping to develop your child's IEP (*check one*):

- Not at all
- Somewhat comfortable
- Very comfortable

21. Does your child currently receive education support services through a 504 Plan at school (*check one*):

- Yes
- No
- I don't know

If **yes**, how comfortable are you in helping to develop your child's 504 Plan (*check one*):

- Not at all
- Somewhat comfortable
- Very comfortable

22. Who are the support personnel that work directly with your child on a regular basis in his/her educational setting (*check all that apply*):

- Educational Audiologist
- Occupational Therapist
- Oral Language Facilitator
- Physical Therapist
- Reading Specialist/Interventionist
- School Counselor
- School Psychologist
- School Social Worker
- Sign Language Interpreter
- Speech-Language Pathologist
- Teacher of the Deaf/Hard-of Hearing (Teacher Consultant for the Hearing Impaired)
- Teacher's aide/Para-professional
- Other (*please specify*):_____

23. What accommodations does your child receive in his/her educational setting (*check all that apply*):

- Closed-captioning of videos/movies/visual aids
- Computer-assisted real-time captioning (CART)
- Extended time for taking tests
- FM system (Sound field or personal system)
- Notetaker
- Special/preferential seating in the classroom
- Other (*please specify*):_____

B. Family Information

24. Your (Respondent's) Name: _____

25. Gender of respondent (*check one*):

- Male
- Female

26. Your Primary Mailing Address: (needed for child's report)

Street: _____ Apt. _____
City: _____ State _____ Zip _____
Phone Number (_____) _____

27. What is your relationship to the child (*check one*):

- Mother
- Father
- Stepparent
- Grandparent
- Guardian (but not parent)
- Other (*specify*): _____

28. What is your ethnicity (*check one*):

- Hispanic or Latino
- Not Hispanic or Latino

29. What is your race (*check all that apply*):

- American Indian or Alaska Native
- Asian
- Black or African American
- Native Hawaiian or Other Pacific Islander
- White

30. What is the **primary** language spoken in your home (*check one*):

- English only
- English primary plus some second language (*specify the second language*): _____
- Bilingual (*specify languages*): _____

31. Please indicate the highest educational level you have attained (*check one*):

- Some High School
- Graduated High School
- GED/Adult Education
- Some College including Community College and Technical Training
- Graduated Two-Year College (e.g., Associate's Degree, LPN)
- Graduated Four-Year College (e.g., BA, BS)
- Graduate School (e.g., MA, MS, MD, PhD, MSW, MBA)

32. What is your **primary** occupation (*Be as specific as possible , i.e., title and major duties*):

33. Is there another **adult** living in your household (*check one*):

- Yes
- No

If **yes**, what is their relationship to the child (*check one*):

- Mother
- Father
- Stepparent
- Grandparent
- Guardian (but not parent)
- Other (*specify*): _____

34. Please indicate the highest educational level attained by the other adult (*check one*):

- Some High School
- Graduated High School
- GED/Adult Education
- Some College including Community College and Technical Training
- Graduated Two-Year College (e.g., Associate's Degree, LPN)
- Graduated Four-Year College (e.g., BA, BS)
- Graduate School (e.g., MA, MS, MD, PhD, MSW, MBA)

35. What is their **primary** occupation (*Be as specific as possible, i.e., title and major duties*):

36. Do you have other children living in your home (*check one*):

- Yes (*please list ages of your other children*): _____; _____; _____; _____; _____
- No

37. To help us characterize the economic status of study participants, please indicate which category best describes the combined annual income, before taxes, of all members of our household for last year (*check one*):

- less than \$15, 000
- \$15,000-\$29, 999
- \$30,000-\$49,999
- \$50,000-\$74, 999
- \$75,000-\$99, 999
- \$100,000-\$129,999
- More than \$130,000
- Decline to answer

38. How often do you or other members of the family read with your child in a typical week (*check one*):

- Never
- 1 or 2 times per week
- 3 or 4 times per week
- 5 or 6 times per week
- 7 or more times per week

39. In a typical week, how often do you or other members of the family read the following items with your child:

	Not at all	1-2 times/week	3-4 times/week	5-6 times/week	7 or more times/week
Catalogues	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Children's Magazines	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Children's Storybooks	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Comic books	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Cookbooks/recipes	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Newspapers	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Online books/websites	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

40. How many children's books do you own (*check one*):

- 1-10
- 11 to 25
- 25 or more

41. How often do you or other members of the family get books from the library for your child (*check one*):

- Never
- Weekly
- Twice a month
- Once a month
- Once every three months
- Twice a year
- Once a year

42. How often do you or other members of the family purchase books from a bookstore or online for your child (*check one*):

- Never
- Weekly
- Twice a month
- Once a month
- Once every three months
- Twice a year
- Once a year

43. In a typical week, how often does your child ask to be read to (*check one*):

- Never
- 1 or 2 times per week
- 3 or 4 times per week
- 5 or 6 times per week
- 7 or more times per week

44. Does your child like to read by himself/herself (*check one*):

- Yes
- No

45. My child and I discuss stories he/she reads (*check one*):

- Never
- Seldom
- Often
- Very often

46. During a typical week of school, how often do you talk with your child about his/her school work/assignments (*check one*):

- Never
- 1 or 2 times per week
- 3 or 4 times per week
- 5 or 6 times per week
- 7 or more times per week

47. How much do you think you can positively affect your child's:

	Not at all	Somewhat	Very Much
Listening skills	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Ability to talk	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Ability to express his/her thoughts	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Reading abilities	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

48. How comfortable are you in troubleshooting your child's cochlear implant if there was a problem (*check one*):

- Not at all
- Somewhat comfortable
- Very comfortable

49. Since your child has received his/her implant, have you ever attended a training, workshop, or other informational meeting about cochlear implants (*check one*):

- Yes
- No

If **yes**, which of the following describe these learning opportunities (*check all that apply*):

- AG Bell workshop
- School sponsored event
- Cochlear implant manufacturer sponsored event
- Hospital/Cochlear Implant Clinic sponsored event
- State Early Hearing Detection and Intervention (EHDI) sponsored event
- Other (*please specify*): _____

Thank you!

BIBLIOGRAPHY

- Adams, M. J. (1990). *Beginning to read*. Cambridge, MA: MIT Press.
- Archbold, S., Harris, M., O'Donoghue, G., Nikolopoulos, T., White, A., & Richmond, H. L. (2008). Reading abilities after cochlear implantation: The effect of age at implantation on outcomes at 5 and 7 years after implantation. *International Journal of Pediatric Otorhinolaryngology*, *72*, 1471-1478.
- Berrettini, S., Forli, F., Genovese, E., Santarelli, R., Arslan, E., Chilosi, A. M., & Ciprani, P. (2008). Cochlear implantation in deaf children with associated disabilities: Challenges and outcomes. *International Journal of Audiology*, *47*, 199-208.
- Bradley, R. H., & Corwyn, R. F. (2002). Socioeconomic status and child development. *Annual Review of Psychology*, *53*, 371-399.
- Buchman, C. A., Copeland, B. J., Yu, K. K., Brown, C. J., Carrasco, V. N., & Pillsbury, H. C. (2004). Cochlear implantation in children with congenital inner ear malformations. *Laryngoscope*, *114*, 309-316.
- Catts, H. W., Hogan, T., & Fey, M. E. (2003). Subgrouping poor readers on the basis of individual differences in reading-related abilities. *Journal of Learning Disabilities*, *36*, 151-164.
- Ching, T. Y., Dillon, H., Day, J., Crowe, K., Close, L., Chisholm, K., & Hopkins, T. (2009). Early language outcomes of children with cochlear implants: Interim

findings of the NAL study on longitudinal outcomes of children with hearing impairment. *Cochlear Implants International*, 10, 28-32.

Connor, C. M., Craig, H. K., Raudenbush, S. W., Heavner, K., & Zwolan, T. A. (2006).

The age at which young deaf children receive cochlear implants and their vocabulary and speech-production growth: Is there an added value for early implantation? *Ear and Hearing*, 26(6), 628-644.

Connor, C. M., Hieber, S., Arts, H. A., & Zwolan, T. A. (2000). The education of children with cochlear implants: total or oral communication? *Journal of Speech, Language, and Hearing Research*, 43, 1185–1204.

Connor, C. M., & Zwolan, T. A. (2004). Examining multiple sources of influence on the reading comprehension skills of children who use cochlear implants. *Journal of Speech, Language, and Hearing Research*, 47(3), 509–526.

Deeks, J. M., & Carlyon, R. P. (2004). Simulations of cochlear implant hearing using filtered harmonic complexes: Implications for concurrent sound segregation. *Journal of the Acoustical Society of America*, 115, 1736-1746.

DesJardin, J. L., & Eisenberg, L. S. (2007). Maternal contributions: Supporting language development in young children with cochlear implants. *Ear and Hearing*, 28(4), 456-469.

Donaldson, A. I., Heavner, K. S., & Zwolan, T. A. (2004). Measuring progress in children with autism spectrum disorder who have cochlear implants. *Archives of Otolaryngology-Head & Neck Surgery*, 130, 666-671.

- Duke, N. K., & Carlisle, J. (2011). The development of comprehension. In M. L. Kamil, P. D. Pearson, E. B. Moje, & P. P. Afflerbach (Eds.), *Handbook of reading research* (Vol IV, pp.199-228). New York, NY; Routledge.
- Dunn, L. M., & Dunn, L. M. (1997). *Peabody Picture Vocabulary Test-III*. Circle Pines, MN: American Guidance Service.
- Dunn L. M., & Dunn D. M. (2007). *Peabody Picture Vocabulary Test-IV*. San Antonio, TX: NCS Pearson.
- Dunn, L. M., & Markwardt, F. C. (1989). *Peabody Individual Achievement Test-Revised*. Circle Pines, MN: American Guidance Service, Inc.
- Edwards, L. C. (2007). Children with cochlear implants and complex needs: A review of outcome research and psychological practice. *Journal of Deaf Studies and Deaf Education, 12*(3), 258-268.
- Edwards, S., Fletcher, P., Garman, M., Hughes, A., Letts, C., & Sinka, I. (1997). Reynell Developmental Language Scale–III. Windsor: NFER-Nelson.
- Eisenman, D. J., Ashbaugh, C., Zwolan, T. A., Arts, H. A., & Telian, S. A. (2001). Implantation of the malformed cochlea. *Otology & Neurotology, 22*, 834-841.
- Elbro, C., Borstrøm, I., & Petersen, D. (1998). Predicting Dyslexia From Kindergarten: The Importance of Distinctness of Phonological Representations of Lexical Items. *Reading Research Quarterly, 33*(1), 36–60.
- Entwisle, D. R., & Astone, N. M. (1994). Some practical guidelines for measuring youth's race/ethnicity and socioeconomic status. *Child Development, 65*, 1521-1540.

- Ezell, H. K. & Justice, L. M. (2005) *Shared storybook reading: Building young children's language & emergent literacy skills*. Baltimore: Paul H. Brookes Publishing Company.
- Fagan, M. K., Pisoni, D. B., Horn, D. L., & Dillon, C. M. (2007). Neurological correlates of vocabulary, reading, and working memory in deaf children with cochlear implants. *Journal of Deaf Studies and Deaf Education*, 12(4), 461-471.
- Fenson, L., Dale, P., Reznick, J.S., Thal, D., Bates, E., Hartung, J., Pethick, S., & Reilly, J. (1993). *The MacArthur Communicative Development Inventories*. San Diego, CA: Singular Press.
- Fowler, A. E. (1991). How early phonological development might set the stage for phoneme awareness. In S. A. Brady and D. P. Shankweiler (Eds), *Phonological processes in literacy: A tribute to Isabelle Y. Liberman* (pp. 97-118). Hillsdale, NJ: Erlbaum.
- Gallaudet Research Institute. (2005). *Stanford achievement test, 10th edition, form A, norms booklet for deaf and hard of hearing students*. Washington, DC: Gallaudet Research Institute, Gallaudet University.
- Gallaudet Research Institute (November 2008). *Regional and National Summary Report of Data from the 2007-08 Annual Survey of Deaf and Hard of Hearing Children and Youth*. Washington, DC: GRI, Gallaudet University.
- Gamse, B. C., Jacob, R. T., Horst, M., Boulay, B., and Unlu, F. (2008). *Reading First Impact Study Final Report Executive Summary* (NCEE 2009-4039). Washington, DC: National Center for Education Evaluation and Regional Assistance, Institute of Education Sciences, U.S. Department of Education.

- Geers, A. (2002). Factors affecting the development of speech, language, and literacy in children with early cochlear implantation. *Language, Speech, and Hearing Services in Schools, 33*, 172-183.
- Geers, A. E. (2003). Predictors of reading skill development in children with early cochlear implantation. *Ear and Hearing, 24*, 59S-68S.
- Geers, A. E., & Hayes, H. (2011). Reading, writing, phonological processing skills in adolescents with 10 or more years of cochlear implant experience. *Ear and Hearing, 32*(1), 49S-59S.
- Geers, A. E., Nicholas, J. G., & Sedey, A. L. (2003). Language skills of children with early cochlear implantation. *Ear and Hearing, 24*, 46S-58S.
- Geers, A. E., Tobey, E., Moog, J., & Brenner, C. (2008). Long-term outcomes of cochlear implantation in the preschool years: From elementary grades to high school. *International Journal of Audiology, 47*(Suppl.2), S21-S30.
- Goswami, U., & Bryant, P. (1990). *Phonological skills and learning to read*. Hove, UK: Erlbaum.
- Hanson, V. L., & Fowler, C. A. (1987). Phonological coding in word reading: Evidence from hearing and deaf readers. *Memory and Cognition, 15*, 199-207.
- Hart, B. & Risley, T. R. (1995). *Meaningful differences in the everyday experience of young American children*. Baltimore, MD: Paul H. Brookes Publishing.
- Hauser, R. M. (1994). Measuring socioeconomic status in studies of child development. *Child Development, 65*, 1541-1545.

- 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.
- Holt, R. F., & Kirk, K. I. (2005). Speech and language development in cognitively delayed children with cochlear implants. *Ear and Hearing, 26*, 132–148.
- James, D., Rajput, K., Brinton, J., & Goswami, U. (2008). Phonological awareness, vocabulary, and word reading in children who use cochlear implants: Does age of implantation explain individual variability in performance outcomes and growth? *Journal of Deaf Studies and Deaf Education, 13*(1), 117-137.
- James, D., Rajput, K., Brinton, J., & Goswami, U. (2009). Orthographic influences, vocabulary development, and phonological awareness in deaf children who use cochlear implants. *Applied Psycholinguistics, 30*, 659-684.
- James, D., Rajput, K., Brown, T., Sirimanna, T., Brinton, J., & Goswami, U. (2005). Phonological awareness in deaf children who use cochlear implants. *Journal of Speech, Language, and Hearing Research, 48*, 1511–1528.
- Jerger, S., & Jerger, J. (1984). *Pediatric Speech Intelligibility Test*. St. Louis, MO: Auditec.
- Johnson, C., & Goswami, U. (2010). Phonological awareness, vocabulary, and reading in deaf children with cochlear implants. *Journal of Speech, Language, and Hearing Research, 53*, 237-261.
- Johnston, J. C., Durieux-Smith, A., Angus, D., O'Connor, A., & Fitzpatrick, E. (2009). Bilateral paediatric cochlear implants: A critical review. *International Journal of Audiology, 48*(9), 601-617.

- Joint Committee on Infant Hearing. (2007). Year 2007 position statement: Principles and guidelines for early hearing detection and intervention programs. *Pediatrics*, 120, 898-921.
- Juel, C. (1988). Learning to read and write: A longitudinal study of 54 children from first through fourth grades. *Journal of Educational Psychology*, 80(4), 437-447.
- Kirk, K. I., Pisoni, D. B., & Osberger, M. J. (1995). Lexical effects of spoken word recognition by pediatric cochlear implant users. *Ear and Hearing*, 16, 470-481.
- Kline, R. B. (2011). *Principles and practice of structural equation modeling* (3rd ed.). New York: Guilford Press.
- Kyle, F. E., & Harris, M. (2006). Concurrent correlates and predictors of reading and spelling achievement in deaf and hearing school children. *Journal of Deaf Studies and Deaf Education*, 11, 273-288.
- Lenneberg, E. (1967) *The biological basis of language*. New York: Academic Press.
- Levelt, W. J. (1992). Accessing words in speech production: Stages, processes and representations. *Cognition*, 1(3), 1-22.
- Leybaert, J. (1993). Reading in the deaf: The roles of phonological codes. In M. Marschark & D. Clark (Eds.), *Psychological perspectives on deafness* (pp. 269-309). Hillsdale, NJ: Erlbaum.
- Ling, D. (2002). *Speech and the hearing impaired child* (2nd ed.). Washington, DC: Alexander Graham Bell Association for the Deaf and Head of Hearing.
- MacCallum, R. C., Browne, M. W., & Sugawara, H. M. (1996). Power analysis and determination of sample size for covariance structure modeling. *Psychological Methods*, 1, 130-149.

- Marschark, M., Rhoten, C., & Fabich, M. (2007). Effects of cochlear implants on children's reading and academic achievement. *Journal of Deaf Studies and Deaf Education*, 12(3), 269-282.
- Marschark, M., Sarchet, T., Rhoten, C., & Zupan, M. (2010). Will cochlear implants close the reading achievement gap for deaf students? In M. Marschark and P. Spencer (Eds.), *The oxford handbook of deaf studies, language and education* (Vol. 2, pp. 127–143). New York, NY: Oxford University Press.
- Mather, N., & Woodcock, R. W. (2001). *Woodcock-Johnson III Tests of Achievement*. Itasca, IL: Riverside.
- Mather, N., & Woodcock, R.W. (2001). *Woodcock-Johnson III Tests of Cognitive Abilities*. Itasca, IL: Riverside Publishing.
- McBride-Chang, C. (1995) Phonological processing, speech perception, and reading disability: An integrative review. *Educational Psychologist*, 30, 109-121.
- Murphy, J., & O'Donoghue, G. (2007). Bilateral cochlear implantation: An evidence-based medicine evaluation. *The Laryngoscope*, 117, 1412–1418.
- Musselman, C. (2000). How do children who can't hear learn to read an alphabetic script? A review of the literature on reading. *Journal of Deaf Studies and Deaf Education*, 5, 9–31.
- Nation, K., & Snowling, M. (2004). Beyond phonological skills: Broader language skills contribute to the development of reading. *Journal of Research in Reading*, 27, 342–356.

- National Center for Education Statistics. (2011). *The Nation's report card: Reading 2011*. (NCES Publication No. 2012-457). Institute of Education Sciences, U.S. Department of Education, Washington, D.C.
- National Institute of Child Health and Human Development. (2000). *Report of the National Reading Panel: Teaching children to read: An evidence-based assessment of the scientific research literature on reading and its implications for reading instruction* (NIH Publication No. 00-4769). Washington, DC: U.S. Government Printing Office.
- Neale, M. D. (1997). *Neale Analysis of Reading Ability—Revised*. Windsor, England: NferNelson.
- Neuman, S. B., & Dickinson, D. K. (2001). *Handbook of early literacy research*. New York: Guilford Press.
- Nicholas, J. G., & Geers, A. E. (2006). Effects of early auditory experience on the spoken language of deaf children at 3 years of age. *Ear and Hearing, 27*, 286-289.
- Niparko, J. K., Tobey, E. A., Thal, D. J., Eisenberg, L. S., Wang, N., Quittner, A. L., & Fink, N. E. (2010). Spoken language development in children following cochlear implantation. *Journal of the American Medical Association, 303*(15), 1498-1506.
- O'Donoghue, G. M., Nikolopoulos, T. P., Archbold, S. M., & Tait, M. (1999). Cochlear implants in young children: The relationship between speech perception and speech intelligibility. *Ear and Hearing, 20*, 419-425.
- Papsin, B. C. (2009). Cochlear implantation in children with anomalous cochleovestibular anatomy. *Laryngoscope, 115*, 1-26.
- Paul, P. (2009). *Language and deafness* (4th ed.). Sunbury, MA: Jones & Bartlett.

- Paul, P. V., & Lee, C. (2010). The qualitative similarity hypothesis. *American Annals of the Deaf, 154*(5), 456-462.
- Peng, S. C., Tomblin, J. B., & Turner, C. W. (2008). Production and perception of speech intonation in pediatric cochlear implant recipients and individuals with normal hearing. *Ear and Hearing, 29*, 336-351.
- Perfetti, C. A. (2007). Reading ability: Lexical quality to comprehension. *Scientific Studies of Reading, 11*(4), 357-383.
- Perfetti, C. A., & Sandak, R. (2000). Reading optimally builds on spoken language: Implications for deaf readers. *Journal of Deaf Studies and Deaf Education, 5*, 32–50.
- Peters, B. R., Wyss, J., & Manrique, M. (2010). Worldwide trends in bilateral cochlear implantation. *Laryngoscope, 120*(Suppl. 2), S17–S44.
- Psychological Corporation. (1999). *Wechsler Abbreviated Scale of Intelligence (WASI) manual*. San Antonio, TX: Author.
- Pisoni, D. B., & Cleary, M. (2003). Measures of working memory span and verbal rehearsal speed in deaf children after cochlear implantation. *Ear and Hearing, 24*, 106S–120S.
- Pisoni, D. B., Cleary, M., Geers, A. E., & Tobey, E. A. (1999). Individual differences in effectiveness of cochlear implants in children who are prelingually deaf: New process measures of performance. *Volta Review, 101*, 111–164.
- Pyman, B., Blamey, P., Lacy, P., Clark, G., & Dowell, R. (2000). The development of speech perception in children using cochlear implants: effects of etiologic factors and delayed milestones. *American Journal of Otology, 21*, 57–61.

- Rashid F. L., Morris, R. D., & Sevcik R. A. (2005). Relationship between home literacy environment and reading achievement in children with reading disabilities. *Journal of Learning Disabilities, 38*, 2–11.
- Reynell, J., & Gruber, C. (1990). *Reynell Developmental Language Scales: US Edition*. Los Angeles, CA: Western Psychological Services.
- Robbins, A. M., Renshaw, J. J., Miyamoto R. T., Osberger, M. J., & Pope M. L. (1988). *Minimal Pairs Test*. Indianapolis, IN: Indiana University School of Medicine.
- Sameroff, A. J. (2009). *The transactional model of development: How children and contexts shape each other*. Washington, D.C.: American Psychological Association.
- Sameroff, A. J., & Mackenzie, M. J. (2003). Research strategies for capturing transactional models of development: The limits of the possible. *Development and Psychopathology, 15*(3), 613-40.
- Scarborough, H. S. (2001). Connecting early language and literacy to later reading (dis)abilities: Evidence, theory, and practice. In S. B. Neuman & D. K. Dickinson (Eds.), *Handbook of early literacy research* (pp. 97–110). New York: Guilford.
- Schirmer, B. R., & McGough, S. M. (2005). Teaching reading to children who are deaf: Do the conclusions of the National Reading Panel apply? *Review of Educational Research, 75* (1), 83-117.
- Schrank, F. A., & Woodcock, R. W. (2008). *WJ III Normative Update Compuscore and Profiles Program* (Version 3.1) [Computer software]. Rolling Meadows, IL: Riverside Publishing.

- Senechal, M., LeFevre, J., Thomas, E. M., & Daley, K. E. (1998). Differential effects of home literacy experiences on the development of oral and written language. *Reading Research Quarterly*, 33 (1), 96-116.
- Sharma, A., Dorman, M. F., & Andrej, K. (2005). The influence of a sensitive period on central auditory development in children with unilateral and bilateral cochlear implants. *Hearing Research*, 203, 134-143.
- Sharma, A., Dorman, M., Spahr, A., & Todd, N. W. (2002). Early cochlear implantation in children allows normal development of central auditory pathways. *The Annals of Otolaryngology, Rhinology and Laryngology*, 111, 38-41.
- Snow, C. E., Burns, S. M., & Griffin, P. (1998). *Preventing reading difficulties in young children*. Washington, DC: National Academy Press.
- Snowling, M. J. (2005). Literacy outcomes for children with oral language impairments: Developmental interactions between language skills and learning to read. In H. W. Catts, & A. G. Kamhi (Eds.), *The connections between language and reading disabilities* (pp. 55–75). Mahwah, NJ: Erlbaum.
- Spencer, L. J., Barker, B. A., & Tomblin, J. B. (2003). Exploring the language and literacy outcomes of pediatric cochlear implant users. *Ear and Hearing*, 24, 236-247.
- Spencer, L., & Oleson, J. (2008). Early listening and speaking skills predict later reading proficiency in pediatric cochlear implant users. *Ear and Hearing*, 29(2), 270-280.
- Spencer, L. J., & Tomblin, J. B. (2009). Evaluating phonological processing skills in children with prelingual deafness who use cochlear implants. *The Journal of Deaf Studies and Deaf Education*, 14, 1-21.

- Spencer, L. J., Tomblin, J. B., & Gantz, B. J. (1997). Reading skills in children with multichannel cochlear implant experience. *Volta Review*, 99(4), 193-202.
- Spencer, P. E., & Marschark, M. (2003). Cochlear implants: Issues and implications. In P. Spencer & M. Marschark (Eds.), *Oxford handbook of deaf studies, languages, and education* (pp. 434-448). New York, New York: Oxford University Press, Inc.
- Svirsky, M. A., Robbins, A. M., Kirk, K. I., Pisoni, D. B., & Miyamoto, R. T. (2000). Language development in profoundly deaf children with cochlear implants. *Psychological Science*, 11, 153-8.
- Svirsky, M. A., Teoh, S. W., & Neuburger H. (2004) Development of language and speech perception in congenitally, profoundly deaf children as a function of age at cochlear implantation. *Audiology and Neuro-Otology*, 9, 224–233.
- Tomblin, J. B., Barker, B. A., Spencer, L. J., Zhang, X., & Gantz, B. J. (2005). The effect of age at cochlear implant initial stimulation on expressive language growth in infants and toddlers. *Journal of Speech, Language, and Hearing Research*, 48, 853-867.
- Traxler, C. B. (2000). The Stanford Achievement Test, 9th edition: National norming and performance standards for deaf and hard-of-hearing students. *Journal of Deaf Studies and Deaf Education*, 5(4), 337–348.
- Tyler, R. S., Fryauf-Bertschy, H., Kelsay, D. M., Gantz, B. J., Woodworth, G. P., & Parkinson, A. (1997). Speech perception by prelingually deaf children using cochlear implants. *Otolaryngology-Head & Neck Surgery*, 117, 180–187.

- Vermeulen, A. M., van Bon, W., Schreuder, R., Knoors, H., & Snik, A. (2007). Reading comprehension of deaf children with cochlear implants. *Journal of Deaf Studies and Deaf Education, 12*(3), 284–302.
- Vlastarakos, P., Konstantinos, P., Papacharalampous, G., Exadaktylou, I., Mochloulis, G., & Nikolopoulos, N. (2010). Cochlear implantation under the first year of age – the outcomes: A critical systematic review and meta-analysis. *International Journal of Pediatric Otorhinolaryngology, 74*, 119-126.
- Wagner, R., Torgesen, J., & Rashotte, C. (2001). *Comprehensive Test of Phonological Processing*. Austin, TX: Pro-Ed.
- Waltzman, S. B., Scalchunes, V., & Cohen, N. L. (2000). Performance of multiply handicapped children using cochlear implants. *American Journal of Otology, 21*, 329–335.
- Wauters, L. N., van Bon, W. H. J., & Tellings, A. E. J. M. (2006). Reading comprehension of Dutch deaf children. *Reading and Writing, 19*, 49-76.
- Wechsler, D. (1991). *The Wechsler Intelligence Scale for Children* (3rd ed.). San Antonio, TX: The Psychological Corporation.
- White, K. R. (2003). The current status of EHDI programs in the United States. *Mental Retardation and Developmental Disabilities Research Reviews, 9*(2), 79-88.
- Woodcock, R. W. (1987). *Woodcock Reading Mastery Tests-Revised*. Circle Pines, MN: American Guidance Services.
- 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.

Zeng, F. (2004). Trends in cochlear implants. *Trends in Amplification*, 8(1), 1-34.

Zwolan, T. A., Ashbaugh, C. M., Alarfaj, A., Arts, H. A., and El-Kashlan, H. K. (2004).

Pediatric cochlear implant patient performance as a function of age at implantation. *Otology and Neurotology*, 25(2), 112-20.