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The contribution of listening and speaking skills to the development of phonological processing in children who use cochlear implants

Linda J. Spencer
University of Iowa

THE CONTRIBUTION OF LISTENING AND SPEAKING SKILLS TO THE DEVELOPMENT OF PHONOLOGICAL PROCESSING IN CHILDREN WHO USE COCHLEAR IMPLANTS

by

Linda J. Spencer

An Abstract

Of a thesis submitted in partial fulfillment
of the requirements for the Doctor of
Philosophy degree in Speech and Hearing Science
in the Graduate College of
The University of Iowa

December 2006

Thesis Supervisor: Professor J. Bruce Tomblin

ABSTRACT

The purpose of this dissertation was to investigate the influences of auditory information provided by the cochlear implant (CI) on the readings skills of children born with profound deafness. I investigated the relationship of *access* to the sound signal provided by the CI on a constellation of skills related to word-reading.

In a preliminary study, I examined the relationship between the early speech production and perception skills of 72 CI users on later reading skills. Using regression analysis, I found I could explain 59% of the variance of later reading skills by early speech perception and production performance.

Secondly, I examined the phonological processing skills of 29 children with prelingual, profound hearing loss with at least 4 years of CI experience. I compared this performance with 29 children with normal hearing, matched with regard to word-reading ability and Socio-Economic-Status. I also compared speech production and perception skills with phonological processing and reading skills.

Results revealed that children with CIs were able to complete tasks measuring phonological processing, but there were performance differences between the two groups. Although the children with CIs had mean standard reading achievement standard scores that were about 12 points lower than the children with normal hearing, the mean standard scores for both groups was within the normal range. Finally, a regression analysis revealed that the Phonological Processing skills accounted for 50%, and 75% of the variance in word and paragraph reading scores for all the children.

In conclusion early speech perception and production skills of children with profound hearing loss who receive CIs predict future reading achievement skills. Better early speech perception and production skills result in higher reading achievement. Furthermore, the early access to sound helps to build better phonological processing skills, which is one of the likely contributors to eventual reading success. Thus, it is reasonable, possible and important to assess the early speech production perception and subsequent phonological processing in children with profound hearing loss who receive CIs.

Abstract Approved: ______________________________
Thesis Supervisor

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Title and Department

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Date

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Iowa City, Iowa

CERTIFICATE OF APPROVAL

PH.D. THESIS

This is to certify that the Ph.D. thesis of

Linda Jean Spencer

has been approved by the Examining Committee
for the thesis requirement for the Doctor of Philosophy
degree in Speech and Hearing Science at the December 2006 graduation.

Thesis Committee: _________________________________
J. Bruce Tomblin, Thesis Supervisor

____
Nancy Ewald Jackson

____
Karla McGregor

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Richard Hurtig

____
Chrisopher W. Turner

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Sandie Bass-Ringdahl

To my Uncle Neil Finnegan, who was the first person to talk to me about higher education as if he knew I was capable of it. To Patricia Quinn, who pushed even harder and would settle for no less than the "terminal degree." To my mother, Virginia Staikoff and my sister Sue Lenz, who never had an ounce of doubt in me and whose simple messages "do your best," "stay true to your heart," and "you will laugh about all this in ten years" have never failed to be true and have kept me on track my whole life. Finally, to my husband Nathan and to my children Kira, Trevor, and Connor. You are all the illuminating force that keeps me going.

What I am is a good rewriter; I never get anything right the first time—I just know how to revise, and revise.

John Irving
The Imaginary Girl Friend

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CHAPTER I

INTRODUCTION

The purpose of this dissertation was to investigate the influences of auditory information provided by the cochlear implant (CI) on the readings skills of children born with profound deafness. The CI stimulates the auditory nerve by converting sound waves into an electrical signal. I investigated the relationship of *access* to the sound signal as provided by the CI and a constellation of skills known to underlie word-reading. In this chapter I will present an overview of how deaf children use the knowledge of the sounds of our language (phonology) to learn to read, and within this context provide the rationale for the study. Next, I will briefly describe the research that indicates prelingually deaf children with CIs perform better with regard to speech perception, production and reading comprehension than their peers who use hearing aids. Finally I will provide a research rationale.

For all children, a first step toward literacy is to have an adequate language base (1992; Kuntze, 1998; Marschark & Harris, 1996). For children with hearing loss, access to a language-rich environment is instrumental for building this base (Marschark and Harrris (1996). In the case of profoundly deaf children who use hearing aids (HAs), there is limited or at best, variable access to many sounds of language. For example, they may have difficulty hearing low-intensity sounds such as /m,n,ng/ or high frequency sounds such as /s, z, f/ (Bench, 1992; Erber, 1972; Kishon-Rabin, Haras, & Bergman, 1997).

For many years, people who are stakeholders in the task of fostering the communication skills of children with severe-to-profound hearing loss have described the relationship between intervention, language and literacy outcomes. This descriptive research describes generally low achievement levels across communication skills including speech intelligibility, spoken and written English comprehension. In particular, children born with profound hearing loss typically graduate from high school reading at the fourth grade level (Goetzinger & Rousey, 1957; Pinter & Patterson, 1916; Pinter & Patterson, 1917; Traxler, 2000). Although this was once considered a functional level, current technological and cultural demands necessitate a 10th or 11th grade reading ability for functional participation in society (Marschark and Harris 1996). Allen (1986) estimates that over 30% of deaf children graduate from high school functionally illiterate.

Instructional methods for children with profound hearing loss have been criticized in the past for failure to incorporate sound-based reading strategies (Hanson, V. L., 1989; Nielsen & Luetke-Stahlman, 2002) (See Chapter II). Lasasso and Mobely (1997) surveyed instructional methods and materials used by teachers of the deaf and found that very few teachers used sound-based (phonological) reading strategies. Furthermore, only 22% of teachers rated their knowledge of reading theory as up-to-date and only 24% rated their knowledge of instructional strategies and variables that affect reading development as current. Yet there is indirect support for using sound-based reading instruction with deaf learners. Skilled reading among deaf readers who do not use CIs is predicted by knowledge of print-to-sound correspondence, speech intelligibility, speech reading skills, and ability to extract phonological information from print (Hanson, 1982; Hanson & Lichtenstein, 1990).

The widespread use of CIs in children provides additional justification for incorporating more sound-based instructional strategies into the reading curriculum for children born with profound hearing loss. Since 1987 when the FDA approved the procedure for children, many with congenital, bilateral, profound loss have received CIs. Compared to their peers who wear hearing aids, these children develop better speech perception (Boothroyd & Eran, 1997; Geers & Brenner, 1994; McKinley & Warren, 2000; Vermeulen et al., 1997) and speech production skills e.g. (Geers & Tobey, 1992; Peng, Spencer, & Tomblin, 2004; Tobey, Geers, & Brenner, 1994; Tye-Murray, Spencer, & Woodworth, 1995). CI users also attain higher levels of language and reading comprehension (Spencer, Barker, & Tomblin, 2003; Spencer, Tomblin, & Gantz, 1997; Spencer, Tye-Murray, & Tomblin, 1998; Tomblin, Spencer, Flock, Tyler, & Gantz, 1999).

Problem Statement

An intact phonological system provides an important foundation for learning to read; however, little is known about the phonological skills of prelingually deaf children who use CIs. Teachers of the deaf have not been educated in assessment or teaching strategies that utilize phonological methods. Instead they have typically used basal reader approaches that favor "whole word" reading. Many educators and specialists are under the impression that it is not possible to assess phonological processing or phonological awareness skills of children with profound hearing loss because these children are unable to complete assessment tasks that include listening to auditorally-presented stimuli and vocalizing the answer.

These impressions are likely incorrect when applied to deaf children who have CIs. Because they perceive and produce speech better than their deaf peers without CIs, they may well develop a more intact phonology, their phonologies may be more testable, and they make more use of their phonology. The limited extant literature suggests that these children develop phonological systems that are stronger than those of their deaf peers without CIs, but weaker than those of their hearing peers.

Children with CIs are more accurate at syllable-counting tasks in spoken words than their peers with hearing aids, (Fryauf-Bertschy, Tyler, Kelsay, & Gantz, 1997). However, it remains difficult for these children to discriminate between finer-grained stimuli. For example, after nearly three years of CI experience, they were only 25% accurate in discriminating between rhyming constants (e.g., dee vs. me, vs tee) in an auditory-only condition (Tye-Murray, Spencer, & Gilbert-Bedia, 1995). Furthermore, children with CIs have shorter working memory spans than children who have normal hearing as measured by digit repetition (Cleary & Pisoni, 2001; Pisoni & Cleary, 2003) or non-word repetition (Carter, Dillon, & Pisoni, 2002). We need to know more about the relationship between phonological skills in children with CIs to find and justify effective ways of teaching them to read.

Research Questions and Hypotheses

<u>Question 1</u>. Do early speech perception and production skills predict later reading achievement skills?

<u>Hypothesis 1.</u> There will be a positive and predictive relationship between earlier speech perception, production and subsequent reading comprehension.

<u>Question 2</u>. Is it possible to establish a series of tasks to measure the phonological awareness and phonological processing skills of CI users?

<u>Hypothesis 2.</u> Children with CIs will be able to complete auditory-only assessment tasks that tap phonological awareness and phonological processing.

<u>Question 3</u>. What is the range of phonological awareness skills in children with more than 3 years of CI experience?

Hypothesis 3. Children with CI experience will display a range of phonological awareness and phonological processing skills, but will perform below word-reading-level matched peers who have normal hearing.

Question 4. What is the relationship between current speech perception, speech production, phonological processing, and reading comprehension skills in children with more than three years of CI experience?

Hypothesis 4. There will be a positive relationship between phonological awareness and phonological processing skills and word-reading skills such that those with stronger phonological awareness and phonological processing skills will have better word reading and reading comprehension skills than those with weaker phonological awareness and weaker processing skills.

CHAPTER II

LITERATURE REVIEW

Emerging research in prelingually deaf children who receive CIs reveals that many attain higher reading achievement levels than their peers who used hearing aids. A substantial literature also supports the view that the cochlear implant (CI) provides better access to speech for most children, and this access results in improved speech perception and production. It is reasonable to assume that this improved auditory input causes the gains in reading comprehension. This chapter will present a review of the major theoretical constructs of phonological awareness (PA) and phonological processing (PP), followed by operational definitions and descriptions of the tasks used to measure the constructs. This presentation also addresses the developmental course of the constructs, views of the relationship of PP to reading, and summarizes models of mature word reading. A summary of the literature on reading skills of the deaf who do and do not use CIs follows, and a significance statement is presented.

Phonological Awareness: The Construct

PA is a complex concept composed of compound abilities. PA is defined as the ability to abstract and manipulate segments of spoken language (Bentin, 1992; Liberman, Shankweiler, Fischer, & Carter, 1974; Mattingly, 1972). The term emerged out of research linking the understanding of the sound structure of a word to the ability to sound-out words in the reading task (Calfee, Lindamood, & Lindamood, 1973). Three distinct levels of PA are proposed; these include breaking individual words into smaller units from words to syllables, then into the onset-rime level, and finally into the phoneme level.

Phonological awareness at the syllabic level: measurement tasks

PA at the syllable level involves awareness that each syllable contains a vowel. Liberman et al. (1974) theorized that syllable awareness arises from the acoustic signal of the spoken word because the vowel provides an energy peak at the vowel center for each syllable. Tasks used to measure PA at the syllabic level may include syllable counting, such as having the participant tap each syllable or count the numbers of syllables in a word (Perfetti, Beck, Bell, & Hughes, 1987). Alternatively, a syllable completion task might require the child to look at a picture (e.g., of a piece of candy). The examiner would say “can” and the child would be expected to say “de” (Muter, Hulme, Snowling, & Taylor, 1997). A shared syllable task might include having a child listen to two words that share the same syllable, and then identify what syllable the two words had in common. For example, the child might hear the two words “party” and “parking” and then identify the syllable (par) that sounds the same in both words (Burt, Holm, & Dodd, 1999). Syllable awareness can also be tested by having the child delete one syllable after hearing the word. For example, the child might be asked to say “toothbrush” then to say “toothbrush” without saying “tooth” (Wagner, Torgesen, & Rashotte, 1999).

Phonological awareness at the onset-rime level: measurement tasks

Onset-rime awareness is the ability to realize that words begin with a sound (e.g./s/) or sound-blend (e.g./st/) and end with a rime unit or vowel and coda (e.g./ing/). In the word *sat* /s/ is the onset and /at/ is the rime. In the word *sting* the onset is the blend /st/ and the rime is the /ing/. Tasks used to measure awareness of the onset-rime level require knowledge that for words to “rhyme” or sound alike, they must share the rime unit. Rhyme tasks also require the knowledge that the rime unit can be separated from the onset. An example of an onset-rime awareness task is for the child to hear two words (e.g. bell/shell) and decide whether or not they rhyme (Burt et al., 1999). Alternatively, the child may be asked to state which word in a set does not rhyme, (e.g. book, king, look) (Bradley & Bryant, 1991). Muter, Hulme, Snowling and Stevenson (2004) also asked children to generate a rhyme for a given word.

Phonological awareness at the phoneme level (phonemic awareness): measurement tasks

A final level of PA is awareness of individual sounds, or phonemic awareness. A phoneme is defined as the smallest unit of sound that affects word meaning, thus the word "house" has three phonemes, including /h/ /au/ /s/. Deleting the final sound /s/, changes the word to "how" altering the meaning of the word. Phonemes, however are abstract concepts; we do not hear the individual phonemes of a word, we hear a blend of the sounds within the sound stream (Liberman, Cooper, Shankweiler, & Studdert-Kennedy, 1967). English has approximately 41 phonemes (depending upon the dialect) comprised of 25 consonants and 16 vowels. Phonemic awareness requires an understanding that words contain individual sounds. Several different tasks are used to measure phonemic awareness including phoneme deletion tasks, "Say sting with out the /t/" Wagner et al.,(1999) alliteration tasks, "Which word has a different first sound: *big, ball, bone, ship?*" (Torgesen & Bryant, 1994; Torgesen, Wagner, & Rashotte, 1994), or phoneme isolation tasks "Which sound is at the beginning of the word *kite*?" (Stahl & Murray, 1994). Additional phonemic awareness include phoneme blending "What word do these sounds make: *m…oo…n*?" (Wagner et al., 1999), phoneme segmentation "How many sounds in the word *jump*?" (Dodd, Sprainger, & Oerlemans, 1989), or phoneme substitution "Say the word *go,* now say the word and change the /g/ to /n/" (Stanovich, Cunningham, & Cramer, 1984).

Levels of difficulty in phonological awareness

Adams (1990) describes five levels of task difficulty for assessing phonological awareness, including the "primitive" skill of remembering and repeating familiar nursery rhymes, identifying that two words rhyme or alliterate. The third level involves isolating the initial sound (onset) from the rest of the word, (rime), the fourth level involves segmenting the phonemes within a word. The fifth level requires the child to add, delete or reorder the phonemes of a particular word.

Stahl and Murray (1994) integrated the concept of linguistic complexity into the construct of PA using a weighting system. Thus recognizing that two words rhyme was assigned a value of 1, but tasks requiring the manipulation of onset *and* rime were assigned a value of 2. Tasks of manipulating the vowel *and* rime had a value of 3, whereas manipulating phonemes *within* a cluster onset or a cluster coda got a value of 4 and 5 respectively. When the authors used the tasks (e.g. blending, full segmentation, partial segmentation, and deletion) to define PA, they found that a single factor accounted for 72.6 % of the variance. When they conducted a factor analysis with weighted levels of linguistic awareness (taking into account onset/rime, or cluster and coda information) and summed the scores at various levels across tasks, they found that a single factor now accounted for 81.7% of the variance. The authors concluded that using 5 levels of linguistic complexity to define PA offered a more complete definition of PA than accounting for task difficulty level alone.

Also according to the results the easiest linguistic level of analysis was analyzing onset and rime, followed by analyzing vowels and codas, then analyzing cluster codas, followed by cluster onsets. Additionally they found that children initially categorized certain blends (st, pl) as units, and would remove the “st” from a word such as “state” when asked to identify the first sound in a word. Later in development, the children recognized that the blends are two different sounds.

Perfetti, Beck, Bell, & Hughes (1987) proposed that phonemic awareness may be a more advanced cognitive skill than is word reading, and the two develop in a reciprocal fashion. In a partial time-lag correlation study, results revealed that deletion tasks tapped a phonemic knowledge that was reciprocal to the reading task. Gains in reading enabled gains in performance on the deletion task, which further enabled gains in reading. They proposed that PA represents a constellation of abilities that center on the ability to segment spoken language. In contrast, performance on a synthesis task (combining sounds to make a word) enabled reading, but reading performance did not increase performance on synthesis. Thus the nature of reciprocity is not clean; some tasks that assess phonological awareness reveal a reciprocal relationship to reading while other tasks do not. See page 18 for more on reciprocal causation and the relation between PA and reading.

Phonological Processing

A broader construct related to PA is *phonological processing (PP).* In some of the literature, the terms are used interchangeably, yet this is not an accurate account. PP encompasses the construct of PA and extends it. According to Wagner et al. (1999), a phonological processing skill important for reading and learning new words is phonological memory, the ability to retain verbal information using the phonological (sound) code. This sound code is stored temporarily into the short-term or working memory and is used to remember a series of digits such as a phone number. Thus we use sound instead o the visual representations of the numbers as a method of remembering. We repeat the number or rehearse the names of the numbers (the phonological representation of the sounds of the names) to ourselves. The term “phonological loop” refers to the mechanism that provides a temporary store for the auditory information (Baddeley, 1992; Torgesen, 1996). This loop has two simultaneously-working parts--the phonological store, and the articulatory control. The phonological store is believed to “record” about 2 seconds worth of sound information, and the articulatory control gives continued input to the phonological loop in order to keep the memory refreshed for longer than 2 seconds. Phonological memory is an important skill used for learning new, spoken and written words (Gathercole & Baddeley, 1990). A deficit in phonological memory could constrain the ability to learn new written and spoken words. Gathercole, Service, Hitch, Adams and Martin (1999) completed two studies that documented the association between phonological memory and vocabulary. They found that this association was strong throughout childhood.

The final, albeit controversial skill possibly involved with phonological processing is rapid naming, which involves retrieving sound information from long-term (permanent) memory. Wagner, Torgesen and Rashotte (1999) propose that young readers first retrieve sounds associated with letters or letter pairs, then they retrieve the pronunciations of common word segments, finally retrieving the whole word. In this view naming speed is predictive of early reading skill because it is a measure of the efficiency of retrieving phonological codes associated with phonemes, word parts or entire words (Shankweiler & Crain, 1986; Share, 1995; Torgesen & Burgess, 1998).

Rapid naming, sometimes referred to as Rapid Automatized Naming (RAN) requires the child to rapidly name a visual array of symbols such as letters, numbers, colors, or line-drawings of common items. While this task has been shown to predict reading, the nature of its relationship to assessment of phonological skills is unclear. Wagner and Torgesson (1987) originally believed that RAN was a phonologically-based skill. Subsequently researchers have proposed that RAN is a measure of several skills including, phonological processing and executive functioning (Denckla & Cutting, 1999), and/or the ability to detect and represent orthographic redundancy (Bowers & Wolf, 1993; Wolf, 1999). Alternatively RAN has been proposed to measure global processing efficiency (Kail, Hall, & Caskey, 1999), and is an index of attention skill (Neuhaus, Foorman, Francis, & Carlson, 2001).

The mechanism behind RAN is not completely understood, but RAN does predict reading achievement. Schatschneider et al. (2002) concluded that poor readers typically have deficits in PA and in naming speed and propose that the two constructs share phonological processing, rather than an independent process that is "nonphonological." For this reason, I have chosen to incorporate a measure of naming speed into the current study.

In summary, the construct of PA is a complex composite of several abilities. PA is part of a broader construct, Phonological Processing (PP), which incorporates phonological memory. In this dissertation, I will use the term PP to indicate the broader, more encompassing construct that includes tasks that rely more on the phonological memory component as described above. There are numerous tasks that can be used to assess PP, but participants must complete four operations during any of these assessment procedures (McBride-Chang, 1995). First, they must listen and perceive the words, which are typically presented in an oral modality. Second they must hold a phonological representation in memory then perform a component of the operation (e.g. manipulate, delete, identify) on an aspect of the speech segment. Finally the participant must communicate the result of the operation they performed, usually in a verbal manner.

Theories of Phonological Development

Many factors (e.g. socio-cultural characteristics teaching methodology, oral language skill, and phonological awareness) contribute to the development of the ability to read. I have chosen to elaborate on the developmental models of phonological development, however because of the relevance of this skill in children who have hearing loss, and the implications of the intervention of a CI on these skills This section will highlight several theories of phonological development.

Modular and Holistic Views

One of the original theories of phonological development is the modular view (Liberman, 1970), which arose from theories of speech perception and assumes that the basic unit of perception is the phoneme. The modular view posits the child has the phoneme structure present in their representations of words at birth and that they develop explicit phonological awareness of the intrinsic phonological knowledge they were born with through the reading process.

Alternately, the holistic view of phonological development purports phonological awareness is an emergent property of vocabulary growth. In early childhood, vocabulary is represented at a holistic level that gradually becomes arranged in terms of phonemic segments in order for the child to make distinctions between words that sound the same (Jusczyk, 1993; Metsala, 1999; Werker & Tees, 1999). These "developmental changes in the nature of basic speech representations play a crucial role in the emergence of phoneme awareness and early reading ability" (Garlock, Walley, & Metsala, 2001, p. 469). As vocabulary grows, more and more words within that vocabulary sound alike (e.g. cry, try; pool, tool). This requires more specialization, and the ability to make finer grained representations of the sounds (Garlock et al., 2001; Metsala & Walley, 1998). In this Lexical Restructuring Model (LRM), words that reside in dense neighborhoods require earlier segmental representation than words residing in sparse neighborhoods. Thus dense neighborhood words (groups of word that differ by one phoneme) influence the development of phonological representations.

Psycholinguistic Grain-sized Theory

Zeigler and Goswami (2005) recently proposed a third, alternate theory of phonological awareness. They concur with the lexical restructuring model that PA may be an emergent property of vocabulary growth for large units within words such as syllables, onsets and rhymes. They extend the LRM proposing that small units require direct instruction. Furthermore Ziegler and Goswami (2005) propose that the beginning reader of languages that have an irregular orthography must deal with three problems: that of availability, consistency and granularity of letter to sound mappings.

The first problem is *availability of stimulus* as it is not possible to have access to all phonological units prior to reading. Rather than hearing the individual phonemes in the word, the sounds are blended into syllables within the sound stream. Thus, phoneme or phonemic awareness is the ability to understand that words are composed of individual sounds. The second problem, *consistency* arises because some orthographic units in languages such as English, which is irregular, can have different pronunciations. Conversely, some pronunciations (phonological units) have multiple spellings (e.g. the spelling unit "ea" can have the pronunciation "ee" as in meat or "short e" as in bread; the sound /f/ can be spelled with "f" "gh" or "ph").

Ziegler and Goswami's third stated problem is *granularity*, which is the size of unit to be learned. There are more words than syllables, more syllables than rimes, more rimes than graphemes (letter or letter combinations that correspond to a sound), and more graphemes than letters to learn when reading. Psycholinguistic grain-size theory states phonology favors larger grain sizes (words), whereas orthography favors smaller, grain sizes (letters), which accounts for why learning to read irregular orthography is difficult.

Psycholinguistic grain-size theory states it is important to understand phonological development in order to understand reading development, and vice-versa because reading development is grounded in phonological processing. Knowing that the beginning reader has the most access to larger phonological units such as whole words, syllables, onsets, onset-vowel or body units or rimes, it would follow that early reading awareness would follow this progression. Similarly, units that are smaller (syllabic or intrasyllabic structures) emerge later and are a property of phonological similarity at the lexical level (Metsala & Walley, 1998). Additionally, the phonological structure and neighborhood, the orthographic neighborhood, plus the level of transparency between the sound-to-grapheme correspondences work together to determine the units and mappings that are important for amalgamating letters to words. The theory presents reading as a continuous process from childhood to adulthood, with the early processes as building blocks for skilled reading.

In summary psychological grain sized theory maintains that successful recoding requires the child to find "shared grain sizes in the symbol system (orthography) and the phonological system of their language to allow for a straightforward and unambiguous mapping between the two domains." The phonological system influences this mapping and the system already has a structure before reading begins. Thus what the child brings to the table before learning to read is important. In other words, if the child begins the reading process with a well developed phonological awareness and knowledge, this will have a positive effect on learning to read.

PA in hearing children—developmental aspects and summary of literature findings

The precursor skills of PA probably begin in infancy. Yet the extent to which normal-hearing infants attend to phonetic detail is unknown. Specifically there is confusion in determining how much phonetic detail infants (and even older children) use to learn words. For example Fennel and Werker (2003) point out discrepancies in the literature. Eight month-old infants can detect the differences between "bih vs dih" in the listening "switch" tasks, but 14 month-old "word learners" are unable to perform the original switch task. Their explanation is that the complex word learning task limits the use and attention to the phonetic detail. There are parallel findings in reading word recognition studies (see Ehri's phases below). The child goes through phases with respect to using either a holistic processing strategy or a more analytic approach to processing written words.

Early speech perception skills are implicit knowledge, but PA is as an explicit skill. Liberman et al. (1974) outlined the developmental progression of PA. They tested phoneme and syllable awareness via a tapping task (tap the number of sounds/syllables within a word) in 135 children who ranged in age from pre-school to first grade. Results revealed an age and a task effect. By the end of first grade, syllable segmentation reached 90% accuracy and phoneme accuracy reached 76% accuracy, a developmental hierarchy of phonological awareness that varies along linguistic levels of complexity (see page 9). For example, primitive levels of analysis utilize larger units such as syllables, while later levels of phonologic awareness require a more fine-grained analysis of phonemes. In the developing reader, syllabic and intrasyllabic sensitivity precedes phoneme sensitivity (Fox & Routh, 1975; Liberman et al., 1974; Treiman, 1992). Thus the developmental sequence for PA progresses from awareness of larger units (syllables, onset-rime), to awareness of individual sounds in words (Caravolas & Bruck, 1993; Stanovich et al., 1984; Treiman & Zukowski, 1991).

In a comprehensive study of English-speaking children in the United States, Lonigan, Burgess, Anthony and Barker (1998) studied the development of PA at the syllable, onset-rime and phoneme levels. Their participants included 356 children between 2 and 5 years of age. The study examined the following abilities: to detect rhyme and alliteration, to blend letters to form words, to blend words to form compound words, and to delete part of a word (elision). Results revealed an age effect across all tasks with the greatest growth in PA seen between the ages of 3 and 4 years. Secondly linguistic complexity affected task performance. All age groups performed better on word-level tasks (blending and deleting items at the word-level) than on syllabic level tasks. Performance on tasks at the phonemic level was the least accurate. There was no performance effect of gender. Additionally there was a correlation between expressive and receptive language test results and PA results for the 4 and 5-year olds, but not for the 2 and 3-year olds. Additional studies have revealed there is a wide range in variability in PA development, and it is only after 4 years of age that one can see stability in performance on PA tasks. Most 4-year-olds demonstrate syllable, and onset-rime awareness (Lonigan et al., 1998; Maclean, Bryant, & Bradley, 1987).

The type of written language system being acquired (e.g. alphabetic, transparent) can influence how one performs on a specific phonological task. Wimmer and Goswami (1994) reported that beginning readers of the German-language were better pseudoword readers than beginning readers of the English-language. German has a more regular orthography; the printed words tend to be a more reliable indicator of how the words sound. These characteristics of the written language (alphabetic, transparent) can also influence the rate one acquires PA, and how one uses PA in reading and spelling.

Caravolas and Bruck (1993) compared Czech and English speaking children on PA tasks. They hypothesized that Czech-speaking children would be better than English-speaking children in the PA task of elision (say "sting" without the /t/). The hypothesis was based on the observation that the Czech written language was relatively transparent (written words sound like how they are spelled), and is characterized by consonant clusters that have high prominence, variety and complexity, compared with English. Results supported their hypothesis and the effect size was similar for reading and pre-reading children, highlighting the contribution of spoken language to the development of PA.

In another study by Cheung, Chen, Lai, Wong and Hills, (2001) English speakers demonstrated superior PA skills compared to Cantonese speakers, who used a logographic (symbol) form of written language. Furthermore, children who used the Guanzghou language with written pinyin (alphabetic form) did better on onset-rime analysis than their Cantonese counterparts who only used the symbolic, written form of language. The findings that written and spoken language experience affects phonological skills have an interesting implication Cheung et al., (2001). It suggests that there is a "mediating function of phonological awareness in integrating sound information derived" from reading and listening (p.227).

The aforementioned studies illustrate that what a child hears and the writing system used, influences how the child reads. If a child utilizes a sound-system where the letters reliably map onto the sounds of a spoken word, the child can read with less difficulty. Children who use CIs may be able to reap some of this advantage when it comes to reading. They may derive more access to sound, which leads to a more reliable auditory signal than do their counterparts with profound deafness. If this is true we should expect them to have an advantage over those peers on tasks that tap phonology. If they hear the /t/ on the end of the word more consistently, when they see that word in print they should be able to make the connection between the word they hear and the word they see to read.

<u>The reciprocal nature of PA</u>

Some argue that PA comes about as a result of learning to read, or the notion of reciprocal causation. We see evidence of reciprocal causation when we examine the phonological awareness skills of illiterate adults. Morais, Bertelson, Cary, & Alegria (1986) compared PA skills in adults who have never received reading training, and with adults who received reading training in adulthood. The former group had significantly inferior phonemic segmentation skills than the latter group, suggesting that PA skills do not develop naturally, but are learned. Furthermore, if PA skills improve after literacy training, this may indicate that one develops the ability to reflect on spoken words *after* learning to read.

In the context of children with hearing loss, it could be that this reciprocal relationship is more evident. For example there could be instances where a child does not hear all the sounds of a word, but comes to realize that there are sounds that are included within the word, only after seeing the word in print. Alternatively or additionally, as mentioned above, some children may come to the reading task with a more developed sense of what words sound like.

The Relationship of PA to Speech Sound and Language Development

In children who have normal hearing, research links speech sound disorder (articulation disorder, or phonological disorder) with later reading deficits (Catts, Fey, Zhang, & Tomblin, 1999; Scarborough & Dobrich, 1990; Snowling, Bishop, & Stothard, 2000). One caveat with this research is that many of the studies use a combined criterion of speech sound disorder *and* language disorder, making it difficult to discern the level to which each deficit contributes to reading difficulty. The emerging picture is that a speech sound disorder and/or specific language impairment (SLI), increases the likelihood of poor performance on PA tasks.

Fazio (1997) found that children with SLI had difficulty learning and reciting nursery rhymes, one of the earliest PA skills. In this study the children with SLI needed many trials and had difficulty with storing each line of the poem. They also had difficulty retrieving the poem from long-term memory after a time delay and there was a correlation between poem memorization and performance on sound detection tasks. This suggests a relationship between the emergence of phonological awareness and memory for linguistic content that relies heavily on phonological memory. Children who scored poorly on sound detection tasks tended to need more trials to learn the poem. The authors concluded that children with SLI had trouble with both storage and retrieval of the phonological information.

Another study by Briscoe, Bishop and Norbury (2001) found that normal-hearing children with SLI had difficulty on tests of phonological discrimination, phonological awareness, and non-word repetition. The discrimination tasks included three indices of phonological skills including the ability to discriminate phoneme identity and sequence pairs of words and non-words; the ability to find the word in a sequence with the same onset or rime, and the ability to repeat non-words. Additionally children with mild-to-moderate sensorineural hearing loss had similar difficulties on the same tasks.

This relationship between language, articulation and PA is somewhat equivocal. Some studies have found children with speech *and* language disorders (not only just speech sound disorders) eventually present with reading problems (Catts, 1993), while others have found a relationship between PA and primary sound disorders (without the presence of language impairments) (Bird, Bishop, & Freeman, 1995; Leitao & Fletcher, 2004). These contradictions have led to the "critical age hypothesis" (Bishop & Adams, 1990) which posits that if the speech sound disorder has resolved by the time the child begins to learn to read and write, the child is less likely to experience problems with learning to read.

Most children who are born deaf who have CIs do not necessarily have a fully resolved speech sound production system by the time they begin to read; however they display much better speech production skills than their peers who do not use CIs. Spencer and Bass-Ringdahl (2004) found that children who were between 12.8 and 27 months at time of implantation and who had 36 months of CI experience produced 69.5 % of their phonemes accurately in a sentence repetition task. Conversely, Smith (1975) found that children born with profound hearing loss using HAs who were age 10 or older, only produced 20% of their phonemes accurately. This increased level of facility with speech production should yield an advantage with respect to the phonological skills related to reading.

Speech Production and Implications of the potential for CI users to develop PP skills)

Children with profound hearing loss who use conventional amplification have speech production scores that can range from 0 to 80% phonemes correct and the average intelligibility rating for these children is 20% (Smith, 1975). Intelligibility scores of CI users, in contrast are much higher. For example Tobey et.al. (2003) measured average intelligibility at 63.5% for 8 and 9 year-old CI users who had a mean of 5.5 years of CI experience. Peng, et al., (2004) measured mean intelligibility rates of 72% after listeners heard two presentations of a sentence. CI users in this study had an average of 7 years of CI experience and ranged in age from 9 to 18 years. Currently, more than any other time in history, these children have the potential to gain access to phonology, possibly using input provided via the cochlear implant.

The Relationship of PA to reading—predictive power

Bradley and Bryant (1983) completed a longitudinal and training study to investigate whether PA skills in pre-schoolers could influence subsequent reading and spelling skills. They studied 403 pre-readers who were between 4 and 5 years of age, finding a significant relationship between a PA measure and scores on standardized reading tests administered three years later. The task used in this case was to have the children listen to a set of words (dog, dip, sun) and then identify which word started with a different sound.

The above findings have been repeated. Share, Jorm, MacLean and Mathews (1984) reported that phonemic segmentation skill at time of school entry was the best of 39 measures in predicting reading success two years later. Subsequently Perfetti et al., (1997) and Tunmer and Nesdale (1985) reported that phonemic segmentation is a necessary, albeit not sufficient, component for reading success. Tunmer and Nesdale (1985) found that if a child could not perform phoneme segmentation tasks, they were unable to read pseudowords (words that follow conventional spelling patterns but are not real words in the language). Adams (1990) suggested that letter knowledge and phonological awareness are the strongest predictors of successful readers.

PA can predict reading achievement and training in PA can effect a change in reading outcome. If children receive training to build their PA skills, the trajectory of their reading growth patterns improves at a faster rate than controls. The training portion of the Bradley and Bryant (1983) study targeted 65 children who had low performance on the PA task. Four groups of children received either sound-categorization training, sound- categorization training combined with letter-to-sound based training using letter manipulation, semantic category training or no training for two years. Results revealed that the children who received both the sound-based training combined with letter-to-sound based training were significantly better readers and spellers after the two years. Their performance exceeded that of the no-treatment group by 9 months for reading ability and 17 months for spelling ability.

A subsequent study by Byrne, Fielding-Barnsley and Ashley (2000) found that 5th graders who had phonologically-based training as preschoolers had superior word-reading skills compared to control children who had not received such training. The training program targeted teaching children about beginning and ending sounds, and about the concept of phoneme sharing. This training effect was maintained 6 years after the training took place. Furthermore the study revealed that children who were slow to achieve PA skills were slower in their rates of reading growth.

The Relationship of PA to reading—effect size

Bus and van IJzendoorn (1999) completed a meta-analysis on the effects of PA training on reading. They used a database and "snowball" analysis to cull 32 articles that used 36 studies investigating the effects of training programs on PA and 34 studies that tested the effects on reading. The meta-analysis revealed that training in PA improves

PA and leads to some improvement in reading skills. The combined effect of US studies was d = 0.73, r = .34 (p <.001) for PA and d = .70, r = .33 (p <.001) for reading. The authors state that PA "should be considered a causal factor in learning to read."

An Alternate View of the Contribution of PA to Reading

There are alternate views regarding the relationship between PA and reading. While numerous longitudinal studies find a significant correlation between early measures of PA and later reading development e.g. (Bryant, MacLean, Bradley, & Crossland, 1990; Jorm, Share, Maclean, & Matthews, 1984; Perfetti et al., 1987; Stanovich et al., 1984) correlation does not equal causation. While Bus and van IJzendoorn (1999) concludes that PA should be considered as a causal factor in learning to read, Castles and Coltheart (2004) have an alternate view. They say a causal link cannot be established until we rule out that a third, unrelated variable is not affecting performance on reading or PA tasks. They also suggest that the direction of this relationship may be reciprocal.

Additionally Scarborough (2005) outlined several concerns with core aspects of the phonological model of reading. Three of her most cogent arguments are that the phonological model is an incomplete way to account for oral to written language difficulties, because there are non phonological language measures such as lexical and grammatical measures that are stronger predictors of reading word reading and comprehension skills, than measures of PA. Secondly she cites studies where severe deficits in decoding and word recognition emerge after third grade in children who demonstrated satisfactory reading skills in the primary grades. Readers who use this type of whole-word sight memorization reading strategy may initially appear to be succeeding at the reading task for the first several years, yet eventually this strategy becomes too cumbersome as words become more morphologically and phonologically complex in the upper grades (Juel, 1990).

Finally, and perhaps most convincing, is Scarborough's argument that "successful reading comprehension is often accomplished by students with severe word recognition and decoding deficiencies" (p14). Jackson and Dollinger (2002) identified a small group of "resilient readers" who had average to above average text comprehension relative to 194 of their undergraduate peers, in spite of having poor decoding skills as measured by a non-word reading task. In addition, these resilient readers displayed difficulties with spelling, word reading and reading speed.

Leach, Scarborough and Rescorla (2003) also describe a subtype of reading disorder that is characterized by word-level difficulty, problems with phonological awareness, spelling, and naming speed, yet general reading comprehension skills appeared to be similar to their non-reading disordered peers. Additionally this subtype had relatively intact listening comprehension, vocabulary and IQ. Bruck (1990) proposed that individuals with this subtype of reading disability are able to use compensatory strategies afforded by strong cognitive and linguistic abilities to compensate for poor decoding and word reading skills. She hypothesized that these "compensated dyslexics" make educated guesses based on context, which enables them to comprehend the material at hand.

The present study may offer new insights into this controversy and offers a chance to test the contribution of phonology to reading development in a group of prelingually deaf children who use CIs, and who demonstrate substantial variability in their auditory skills and their speech production skills. If I find that those with better phonology become better readers, this supports the notion that phonology contributes to reading development, that access to even an imperfect auditory signal is facilitative. Conversely, if there is no contribution of phonology to reading outcome, this will demonstrate the merits of alternate theories of what contributes to reading success, and will support the observation of Scarborough (2005), that reading can be accomplished without strong phonological skills.

The Skill of Reading

In this section of the literature review I will summarize models of how we believe mature readers learn to read, addressing the collection of skills related to reading (e.g. word identification, theories of word reading, and comprehension). Next, I will review the literature about what we do and do not know about how children with hearing loss learn to read, and concentrate on the challenges of assessing the reading process in individuals who have compromised hearing and articulation skills. The final section of this chapter will summarize the significance of the current study.

Models of reading

In order to learn how to read, children need to learn how to decode the visual symbols on the page to match the sounds of their language; they must be able to take the printed word and translate it to speech. To do this, readers must use their knowledge of symbol-to-sound correspondence. Thus decoding requires phoneme awareness yet as Ziegler and Goswami (2005) point out, decoding in the irregular English orthography is complex. Some letters consistently represent a specific sound, (e.g. the “p” usually represents the unvoiced, bilabial stop /p/). In English, however there is variability between letter and sound correspondence, especially given the context of a specific letter. If the “p” is followed by an “h”, the corresponding sound is typically /f/. Additionally, knowing that a word begins with the letter “p” does not indicate anything about the meaning of that word. In order to learn how to read, the child needs to learn how to use phonological decoding or to map the symbol to the sound. Once this has been accomplished, the child can access words they have heard before, but have never seen in print (Ehri 1992). This skill becomes a watershed in the reading process.

Theories of Word Recognition

Research examining word-recognition skills has emphasized the importance of efficient word-reading as a precursor to comprehension. I will briefly present a summary of several of the basic theories, then I will summarize two models of reading designed either to deal with mature reading, (e.g. dual-route cascading model) or broader in scope, (e.g. connectionist models) which are account for both mature reading and reading acquisition. Finally I will describe two approaches (e.g. analogy, and Ehri’s phases) that are developmental in nature and describe the changes children make as their reading skills mature.

Dual-Route Models

The dual-route model of word recognition is the core of all current theories of skilled word reading in some form (Jackson & Coltheart, 2001, p. 39). There are two, separate dual-route theories, one for reading aloud and one for single word comprehension. I will first summarize the generic dual route model for reading words aloud. Figure 1, taken from Jackson and Coltheart (2001) provides a schematic representation of the theory. In general, they propose that there are two ways to read a printed word, one is to retrieve a whole-word pronunciation, and the other is to use knowledge of letters and sounds at a subword level, that is a dual-route model of reading.

This figure shows that there are two procedures to convert graphemes to phonemes. Both routes start off similarly with the grapheme identification stage, and end similarly, with the phoneme activation stage. On the left side of the figure (the lexical activation route), the specific importance is on grapheme identity, and information about the properties and type of script is disregarded.

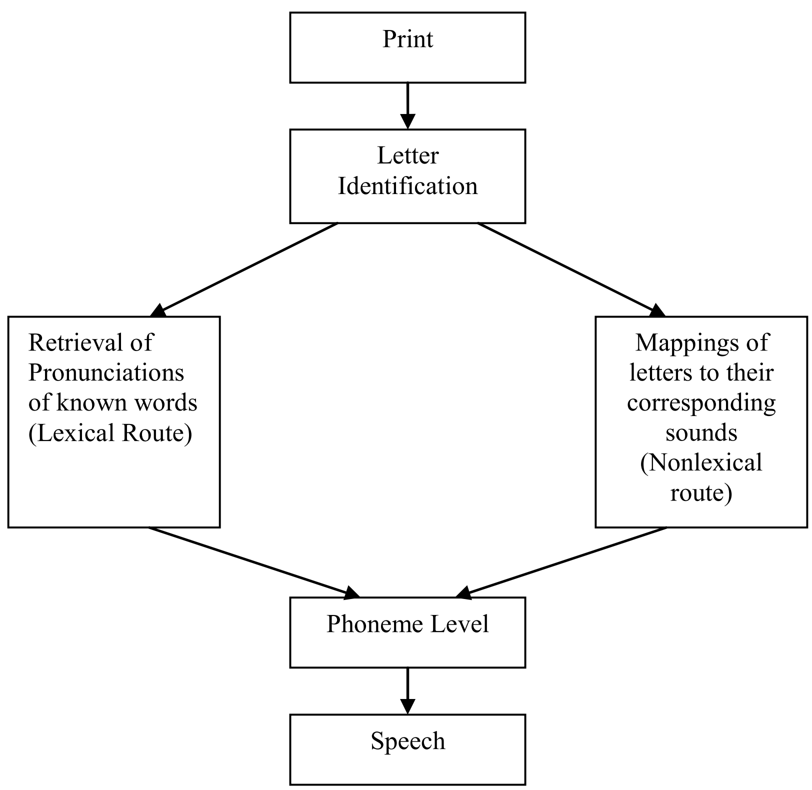

Figure 1. Generic dual-route model of reading taken from Jackson and Coltheart 2001p.41).

After letter identification, the whole-word pronunciation is retrieved, and the word can be said aloud. Only the lexical route can read exception words for correct pronunciation.

On the right side of the schematic is the nonlexical route, which indicates that after graphemes are identified, they are converted to sounds and thus phonological assembly takes place. The two routes are not independent of each other; some processes happen in both pathways, and some happen only in one pathway. Word type determines which path sets the word's pronunciation. Words that have an atypical spelling-to-sound relationship, (such as bought, yacht, borough) are considered irregular. Regualr words follow the typical spelling-to-sound correspondence (e.g. plant, drop, luck).

Finally there is the case of the pseudoword, which is a word that is pronouncable, but does not refer to a real word within a lexicon. Only the lexical route can read exception words for pronunciation. Conversely, the nonlexical route cannot read exception words because they do not follow typical letter-to-sound conventions (Jackson and Coltheart 2001 pp43). Additionally, the nonlexical route enables the reading of pseudowords aloud. Because it is not possible for the system to determine what type of word is about to be read in advance, the theory proposes that both routes are utilized simultaneously.

Figure 2 presents the dual route theory of word *understanding* taken from Jackson and Coltheart (2001 p 67). There is a difference between recognizing a printed word and comprehending that same word. For example, one can recognize whether a printed word is a real word or a pseudoword, yet not have an understanding of the word meaning. The crux of this theory is that there are two components that feed into the semantic system;

orthographic processing, (which feeds into the phonological representation) and the phonological representation itself.

The role of the phonological representation is somewhat controversial. While there is agreement that phonology is important for extracting meaning form print, the degree of importance of this role is in dispute. Some literature refers to “addressed phonology” and other literature refers to “assembled phonology.” Addressed phonology refers to extracting meaning from the whole word (i.e. the whole lexical entry). In contrast, assembled phonology refers to extracting the sound and meaning of the word by assembling the word on the basis of spelling-to-sound correspondence. Addressed

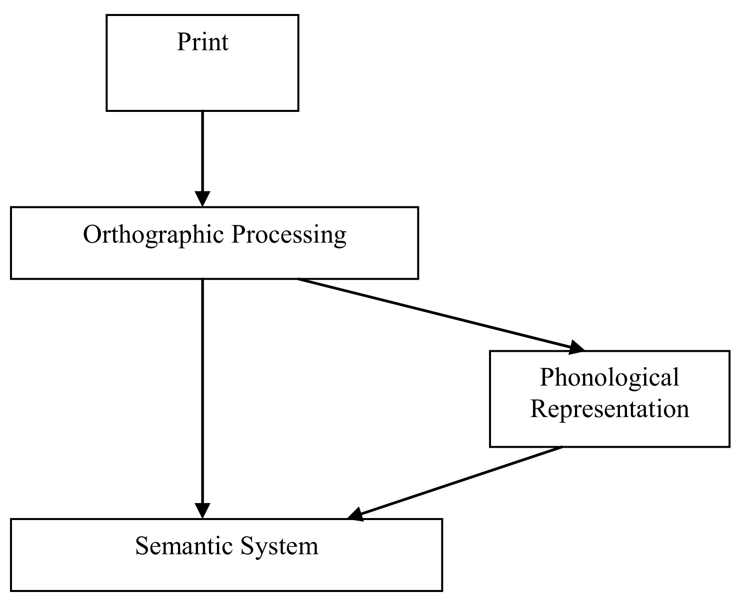

Figure 2. Dual-route theory of word understanding from Jackson and Coltheart (2001 p 67).

phonology may play either a central role or a back-up role in word reading. In the Dual Route theory, word identification via both routes involves addressed phonology, yet only the non-lexical route involves assembled phonology.

Connectionist models

Connectionist models emphasize the importance of phonological knowledge to word reading. The work of Seidenberg and McClelland (1989) was an influential beginning and subsequent work has expanded on their original paradigm. Connectionist models propose similar processing for both regular and irregular words. This processing is through an interconnected path (rather than dual-route) that involves orthography, phonology and semantics. Harm and Seidenberg (1999) provide a detailed description of how the models are implemented, but I will provide a brief summary based on their information. In a connectionist model, it is important to have phonological knowledge in order to process words that are new, words that are familiar and regular, and words that are familiar and irregular. In addition, connectionists propose that grapheme-to-phoneme connections are *emerging properties* of the system, rather than specific grapheme-to-phoneme *representations.* Another key aspect is the proposal that gradual acquisition of the knowledge of relationships between the spoken and written words happens through an excitatory and inhibitory process. For example, the connections *between* orthographic, phonological and semantic units are strengthened though learning and access to the entire representation of a specific word. The connections for words that *share* similar orthographic, phonological or semantic properties gradually inhibit over time.

An important finding has emerged from connectionist reading theories of Harm and Seidenberg (1999). If the phonological unit in the computer model was impaired, (i.e. if they decreased phonological awareness within the model) the computer was not as proficient with reading non-words, and with learning new words. Connectionist models provide the notion of using these frameworks to conceptualize models for teaching of reading. Gillon (2004, p. 22) proposes that teaching methods should emphasize strengthening the connections between orthographic, phonological and semantic networks. She suggests that a starting place is to target PA in order to allow the child to use phonological information to make connections between orthographic and semantic information during reading and spelling tasks.

Descriptions of Reading Development

Analogy approach

Words with both regular and irregular spellings (can, pan, van; right, sight, light), can be accessed by analogy. Analogy strategies of reading (Glushko, 1979; Goswami, 1994) propose that readers access the pronunciations of words that have similar spellings, as opposed to using grapheme-to-phoneme correspondence. Children can use known words to read unknown words by analogy. Goswami and Bryant (1992) advocate for teaching children to read using the linguistic units of onset and rime, so they can use this as a strategy for decoding new words. Pressley (2002, p. 159) encourages teaching “word families” to new readers. Word families are groups of words that have common endings (e.g. –ame). This approach encourages the child to use knowledge of the rime, as well as the sounds made by the onset.

Phase Theory

Another description of the learning-to-read process comes from Ehri (1998), who is specifically interested how skilled readers come to read words. She proposed four phases for word-reading. These include the *pre-alphabetic, partial-alphabetic, full-alphabetic* and *consolidated-alphabetic* phases. In the *pre-alphabetic* phase, beginners remember how to read sight words by making connections between selected visual attributes of words and the word pronunciations, then storing these associations in memory. Gough, Juel and Griffith (1992) found that children in this phase are very dependent upon the whole visual cue; even a thumbprint on a word-card can serve as an intrinsic cue for the child to recognize the word. Frith (1985) refers to this phase as logographic because letter-sound relations are not involved in the connections, and there is little or no phonemic correspondence (letters are not stored in memory). In the *partial-alphabetic phase*, the child learns to form some connection between some letters and sounds. For example, first and final letters are more salient and the child remembers them more often. In this phase, sometimes called phonetic cue reading, the child begins to learn letter-sound correspondences, which is advantageous, as the phonetic cue yields a system by which to remember the words. In the *full-alphabetic phase*, readers read the sight words by making a complete connection between the written letters and the phonemes in pronunciation. This phase has also been called the "spelling-sound" stage (Juel, 1990), the "cipher-reading stage" (Gough and Hillinger, 1980), and the "alphabetic phase" (Frith 1985). In this phase, the graphemes (letters) symbolize the sound in the conventional spelling system. Now the child can form a bond between the spellings and the pronunciations, and commit them to memory. In this full alphabetic phase, decoding new words becomes easier through blending letters. Full-phase readers form sight words and commit them into memory.

Finally, in the *consolidated-alphabetic phase* of reading, also called the *orthographic phase* (Frith, 1985) the child is able to operate using multi-letter units that are larger than letters (e.g. onset combinations, rimes, syllables, plus affixes and root words which become morphological units). Now the reader can quickly recognize common letter patterns such as *ing, ment, ed,* and the connections are now analytic and systematic. Thus this new ability to use "chunks" facilitates the learning of longer sight words.

One assumption that is shared by most of the word-reading theories or approaches is that for the skilled reader, the phonological route is a back-up mechanism that comes into play when the word is not immediately recognized; whereas for the beginning reader, the phonological route has a more critical role (Jorm & Share, 1983). At the most basic level, learning to read involves two fundamental processes: decoding and comprehension (Gough & Tunmer, 1986; Hoover & Gough, 1990). As children become more proficient at the reading process, the decoding process becomes more automatic, which allows more attention for comprehension (Ehri, 1998). Children with normal language and listening skills acquire comprehension skills as they learn to speak, and Hoover and Gough (1990) illustrated that listening and reading comprehension are similar processes. Yet, children do not learn how to decode print simply through talking and listening, or even through listening to their parents read to them. Ehri p.5 (1998) states

"The brain is specialized for processing spoken language, but it has no special central equipment for processing written language…written language must penetrate and gain a foothold in the central equipment used to process speech. Graphemes must become attached to "deep" phonemes, not simply to "surface" sounds within words. Such penetration and attachment, however, are not straight-forward steps, because speech is seamless on the surface, with no breaks signaling phonemic units. Special experiences are needed to engage the brain in deciphering print."

Summary: different paths to reading success and failure

The above descriptions offer several explanations of how reading skills might develop. These frameworks illustrate multiple explanations of how the reading process could work, and multiple opportunities for disruption. While certain skills appear to be necessary (e.g. word recognition), the literature reveals that resilient readers can have deficits in some areas (e.g. spelling, speed of processing), yet they can compensate well enough to succeed in post-secondary educational settings.

Similarly, what skills do children who are hard-of-hearing and/or deaf acquire in their learning-to-read process? Do they function as a hearing, resilient reader might function in the sense that compensatory strategies overcome deficit areas? Is the task of word recognition completed in the same way as hearing children or alternatively is there an alternate route these individuals use?

Reading Skills of Hard-of-Hearing and Deaf Individuals

Paul (1996) attributes decreased levels of world knowledge, smaller vocabulary, and poor reading strategies as contributors to reading deficits in children with hearing loss. Before early identification of hearing loss and early intervention, deaf children frequently began reading at the same time their spoken language development was emerging. Overall reading skills in the deaf have been intractably low.

At the turn of the twentieth century Pinter & Paterson (1916, 1917), revealed that the educational level of typical 18-19 year old students was commensurate with those of the typical 8-9 year old hearing child. In the middle of the twentieth century Goetzinger and Rouzey (1957) reported that the mean achievement levels for children having had 12 years of education was equivalent to hearing children at grade 4.5. Furthermore, the gap in achievement between hearing and deaf children increased with age. Traxler (2000) continued to find a pattern of low achievement, with only 3% of the 18 year-old or older deaf individuals reading at levels commensurate with their hearing peers. There is also an increase in disparity between the actual grade level and the achieved grade level status as the children age. Yoshinaga-Itano and Downey (1996) found that the gap ranged from a 1.5-year difference at age seven and widened to a 9-year deficit by age seventeen.

Reading Deficits in the Deaf

Several studies have evaluated reasons for the poor reading skills in the deaf, specifically looking at decoding and word recognition. Some early studies indicated that that deaf readers used an assembled phonology approach, while subsequent studies indicate they use whole-word reading strategies. Dodd and Hermelin (1977) completed a study examining phonological access of deaf readers. Participants read aloud homophonic words (e.g. rain and reign). Results indicated that over half of the words in the pairs were pronounced differently (e.g. rain pronounced as "rein" yet reign was pronounced "rey-gun"). Thus the study concluded that the readers were using grapheme-to-phoneme correspondence (GPC) rules in order to pronounce words that were unfamiliar. This is indicative of using an assembled phonology.

Merrills, Underwood and Wood (1994) completed a study that examined the use of phonological process for word recognition and challenged the findings of Dodd and Hermelin (1977). Participants were prelingually deaf readers who were between eleven and fifteen years of age. They used regular words, exception words, pronounceable pseudo words, and non-words (e.g. went, once, flup, slxsh), asking participants to decide whether the stimuli were or were not English words, then press a button indicating "Yes" or "No" as fast as possible. Response speed and accuracy were recorded. Results indicated that deaf and hearing readers use the printed cues to access the meaning of words, but deaf readers were slower and less accurate than hearing readers were. In addition, deaf readers were able to identify low frequency, exception words, but they were less accurate than their hearing counterparts were. The study concluded that deaf readers were not as efficient as their hearing peers in visually processing, yet they used a visual, rather than phonological strategy for lexical access of low frequency or exception words. The results call into question the results of Dodd and Hermelin (1977).

Treiman and Hirsh-Pasek (1983) investigated whether second-generation deaf adult readers decoded words using articulation, fingerspelling or signs. They found the participants recognized the whole word, and mapped the word to signs. Twenty years later, Wauters, Knoors, Vervloed and Aarnoutse (2001) completed a review of four studies done in the Netherlands on word decoding in deaf children. Results indicated the children used a whole-word recognition strategy, and that word recognition was correlated with the availability of a sign for the word.

In summary, the few studies that document the decoding and word learning skills of deaf and hard-of-hearing children suggest they tend to use a whole-word recognition approach, and a more visual than sound-based processing approach. However, the data are limited and we do not know whether it would be facilitating or possible to use a more sound-based approach to teach reading with children who are deaf and who use cochlear implants. The aforementioned studies do not report about the relationship between scores on hearing tests and the word-reading approach used (e.g. visual, whole-word or phonological).

Implications of the role of PP in CI users

There are instances where individuals with normal hearing obtain successful reading comprehension skills despite poor phonological awareness skills. What happens to an individual who brings a hearing loss to the learning-to- read process? The reviewed literature reveals they struggle to surpass a fourth-grade reading level. They also tend to have poor speech intelligibility, lowered language achievement levels and poor speech recognition skills. Do people with hearing loss who do learn to read well function in a similar manner to the well-compensated reader who has poor phonological awareness skills? Do hard-of-hearing individuals learn to rely on strong cognitive and linguistic skills to achieve good comprehension skills? We know that it is not necessarily the case that these individuals have strong language skills, so before this question can be answered, we need to review the literature on the phonological processing skills of the hard-of-hearing in order to discern the role of phonological awareness in reading for individuals with severe to profound hearing loss.

Phonological Skills of Children with Prelingual Hearing Loss

There is reason to believe that PP skills in children who are deaf relate to speech production ability. Conrad (1972b) found a relationship between speech intelligibility and phonological awareness in children who were deaf. Leybaert and Alegria (1995) replicated these findings. Hanson and Fowler (1987) found that in deaf college students, those with better speech intelligibility had also better phonological awareness skills.

Moreover, we find there is a correlation between, listening and speech production skills, (Gold, 1978; Markides, 1970; Osberger, Maso, & Sam, 1993; Smith, 1975). It could be that better speech intelligibility is a reflection of basic phonological knowledge that is coded in the act of articulating the sounds. Thus, we may extend this finding to state that better access to the sounds of a language yield better phonological awareness and even phonological processing. Burkholder and Pisoni (2003) investigated the relationship between speaking rate and memory span, in pediatric CI users to see whether articulation rate in a recall task would reflect subvocal verbal rehearsal speed in this population. The authors investigated pause duration and the issue of whether it reflected time spent scanning and retrieving items from short term memory. Previous work by Cleary, Pisoni and Geers (2001) had demonstrated that deaf CI children had significantly shorter working memory spans for verbal and spatial patterns than did their normal-hearing peers. Burkholder and Pisoni (2003) hypothesized that if the CI children had lower memory span, it would be related to a reduced efficiency of verbal rehearsal and/or scanning processes. They suggested that this would be an offshoot from the early linguistic deprivation that the children received before receiving CIs. The results of the study found that the participants (i.e. deaf, CI users who were between 8 and 9 years of age) had shorter digit spans than their normal-hearing age-matched peers.

Leybaert and Alegria (1995) point out that speech intelligibility may be a measure of the "mental model" of speech, and a measure of phonological skills. Raitano, Pennington, Tunick, Boada and Shriberg (2004) have reinforced this idea. They found that children who had persistent speech sound disorders into the school-age years also had reading difficulties, concluding there is "a link between the developmental mappings of the acoustic signal onto phonological representations through the precision of articulatory gestures."

Challenges of PA assessment in Children who are Hard-of-Hearing

The decreased literacy levels of deaf and hard-of-hearing may be related to poor phonological processing skills. Mussleman (2000) emphasized that deaf children must achieve proficiency with phonological processing in order to break the persistent pattern of reading failure. Leybaert (1993) attributed the poor reading achievement in the deaf and hard-of-hearing to programs that failed to address phonological components of the reading task. There are just a few studies reporting on the phonological processing skills in deaf children, and those that do use inconsistent testing methods. Some studies look for evidence of phonologic re-coding of whole words, (e.g. via memory tasks, or interference on stroop tasks), while others look spelling skills as a reflection of PA. James et al., (2005) offers a rationalization that one of the reasons for the dearth of literature on PA in the deaf children is due to methodological concerns stating that oral administration of tests is inappropriate, and therefore researchers have resorted to picture-based tasks, and pointing. Additional obstacles include participants who have decreased speech production intelligibility, decreased access to stimuli presented in an auditory modality and overall methodological concerns regarding how to present stimuli and to judge productive answers for tasks such as pseudo word reading.

Studies with Equivocal Results

In spite of these assessment challenges the literature reveals an overall pattern of deficit in the area of PP, with variation regarding the degree to which these skills do develop. Conrad (1972a) used a short-term memory task for printed words in two experimental contexts: the first set used words that rhymed such as “do, few, who, zoo, blue;” and the second used words that were visually similar (with regard to printed word-shape) such as “bare, bean, door, furs, have.” He assessed the patterns of errors made on the memory task as a way to gain an idea of how the children were internally representing the words, with the idea that phonologically coding the words would result in more difficulty recalling the rhyming words, whereas visually coding the words would result in more difficulty recalling the visually similar words. His analysis revealed that the deaf teenagers made more errors on the rhyming words. While subsequent work has revealed that word-shape does not necessarily capture what contributes to visual similarity (Perea & Rosa, 2002), Conrad's study also found an association between speech intelligibility and error types. Those with better intelligibility tended to produce more phonologically based errors than those with less developed speech skills. Leybaert (1993) substantiated and extended the Conrad's findings to children who were educated in auditory oral programs as well as in total communication programs.

Harris and Beech (1998) completed a longitudinal study of phonological skills in young hearing and deaf children in the context of implicit phonological awareness (IPA) and explicit phonological awareness (EPA). The former is the ability to analyze words into constituent sounds at the levels of the syllable or subsyllabic unit, and the latter is the ability to detect and manipulate phonemes within words. They predicted that prelingually deaf pre-readers younger than age 6 would come to the learning-to-read task with less IPA and make significantly less progress than would a control group of hearing peers who were matched for nonverbal IQ level. They measured implicit phonological awareness using an "odd one out" paradigm. The child looked at a series of three line drawings (doll, cot, dog) and had to choose the picture that didn't belong. Additionally they administered a single word comprehension task and a short sentence completion task

Results indicated that there was a ceiling effect for the hearing children on the tasks, whereas the children who were deaf varied considerably on a number of measures, including implicit phonological awareness, oral ability, and familiarity with British Sign Language and fingerspelling. Overall, the deaf children made significantly less reading progress than their hearing peers over the 1st year of schooling, and scored significantly lower on the test of rime and onset awareness. The reading progress of the deaf children positively correlated with speech intelligibility, rime/onset awareness, and language comprehension. Additionally there was a positive correlation between language comprehension with signing and fingerspelling. One year later, the deaf children were reassessed. They continued to display delayed reading skills, and the pattern of correlation was essentially the same.

Leybaert and Alegria (1993) used a pseudo-word task to provide evidence of phonological encoding in deaf participants. The authors also found that on a stroop task color words produced the most interference if response mode was voice, and least interference if response mode was manual (to push a button) for both deaf and hearing children. This suggests that some of the deaf children had automatic access to word meaning and to word pronunciation. Performance on homophonic pseudo-words of incongruent color words also produced interference with output forms for pronounceable pseudo-words. The deaf children consistently failed to show an interference effect from words that were *related* to the color, but these words interfered with performance for the hearing controls. Taken together these results indicate deaf children have access to phonological representations; however, they approach the task of reading with significantly fewer words that they automatically activate than hearing children do. There was no relationship between their access to phonological information and reading ability in this study, however.

Waters & Doehring (1990) made an interesting observation in a study of orally educated children and adolescents. They found evidence that these children used phonological coding in short-term memory, but this skill did not relate to reading achievement as measured by reading vocabulary and *Passage Comprehension* testing on the Stanford Achievement Test. Speed and accuracy of word identification predicted reading scores. Additionally, reaction times and error rates on a lexical decision task were the same for phonologically regular and irregular words, which suggests a lack of reliance on phonological assembly.

In summary this literature reveals that there is reason to believe that it is important to pursue the case of PP in children with hearing loss. It appears as if these children are using some phonological information in reading, but they have difficulty efficiently or consistently accessing sound information. Hanson (1989 p. 53) made a very powerful statement "to assume deaf readers lack access to phonology because of their deafness is to confuse their sensory deficit with a cognitive deficit."

The Cochlear Implant and Phonological Awareness

While there are a handful of studies that have examined reading comprehension outcomes of children with CIs, few have examined the development of phonological awareness in children with prelingual deafness who use CIs. Despite this void, researchers and educators of the deaf have called for increased PA training programs (Corcoran Nielsen & Luetke-Stahlman, 2002). This makes it essential that researchers provide a baseline from which to measure changes and improvements in these skills. As a start, I will briefly present the general, outcome studies pertaining to reading in children who use CIs, as well as the one published study to date that has assessed PA skills in children with CIs.

The earliest reading investigation, completed by Spencer, Tomblin and Gantz (1997), revealed that over half of the 40 children studied had reading levels exceeding their peers who with HAs. CI participants in the study had a mean age of 11.2 months and they obtained *Passage Comprehension* scores that were at or within 8 months of their grade level. A subsequent study by Connor and Zwolan (2004) used structural equation modeling to identify the factors associated with CI users and better reading achievement. These factors identified included age of implantation, vocabulary level, language level, and Social Economic Status of the family. This study however did not include the variables pertaining to phonological awareness. A third study by Geers (2003) investigated word reading and comprehension skills of 181 prelingually deaf 8 and 9 year-olds who received their CIs before age five. Her results revealed that over half of the children achieved scores within the average range on standardized word reading and comprehension tests. Additionally reading outcome was predicted by linguistic competence and speech intelligibility, but the study did not evaluate PA skills.

Aside from these outcome studies, there is only one study reported in the literature pertaining to how well children with cochlear implants develop phonological awareness. James et al., (2005) looked at syllable, rime and phoneme awareness in profoundly deaf children who used CIs. They found that the children were able to demonstrate phonological awareness at the syllable level, with less accurate performance at the rime and phoneme level. This study did not collect information on speech production or speech perception skills nor did it look at reading achievement levels in relation to phonological awareness skills.

Summary of Existing Research and Contributions of Proposed Study

In hearing children, evidence indicates that the ability to discriminate sounds to form word boundaries supports the development of spoken language, yet there is conflict about whether the unit of organization is the phoneme or the syllabic unit (Chomsky &

Halle, 1968; Lindblom, MacNeilage, & Studdert-Kennedy, 1984). Even so, Fowler, (1991) proposes that there are developmental changes in phonological representations that will “set the stage” for the development of phoneme awareness, and eventually reading. Specifically she proposes that in early childhood, vocabulary is represented at a holistic level that gradually becomes arranged in terms of phonemic segments. Others have supported this notion, finding that as vocabulary expands, phonological representations restructure and become more specialized (Jusczyk, 1993; Metsala, 1999; Werker & Tees, 1999). Swan and Goswami (1997) propose that when we assess PP in hearing children we measure how well the underlying phonological representations are organized.

What happens when hearing is compromised, and the child does not necessarily have access to the same phonetic information that hearing children have? Does the auditory information from the CI yield enough information to allow the child to develop at least holistic vocabulary representations, which functions, in part to “set the stage” for developing phonological awareness?

Although spoken language and phonological processing are related and strongly predictive of reading success, there are cases where compensated dyslexics do achieve relatively adequate levels of reading comprehension despite weak PP skills (p. 25). In children born with profound hearing loss who have CIs, we see a pattern of improved reading comprehension over that of children who use HAs. Are these children merely well-compensated, poor decoders? Alternatively have they been able to access enough phonetic information to facilitate reading?

Finally, in individuals who are hard-of-hearing, we see a large range in language and speech proficiency, phonological processing ability and reading comprehension ability. There is very little systematic investigation of the relationship between hearing proficiency, speech proficiency, PP and word reading. Furthermore there are few tools to assess PP skills in children with hearing loss.

There are several problems and challenges in studying how children with hearing loss learn to read. First of all there has been little research looking into the relationship between speech perception, speech production and word reading skills in children with profound hearing loss and in children who use CIs. We have an incomplete model of how PA skills relate to their reading development. We do know the following about children with profound hearing loss who wear traditional amplification: (a) some show evidence of using phonological processing and sound-based decoding strategies; (b) the subset who use sound-based decoding tend to have higher reading comprehension; and (3) those who have better speech production also have better phonological processing.

The finding that children with profound deafness who use CIs perform better on reading comprehension than do their counterparts who use HAs, provides more confirmation that the additional access to sound provided via the CI is associated with better reading. I propose, given the above converging evidence, that this study will illuminate the relationship between speech perception, speech production and reading skills in CI children, documenting the contribution of phonological awareness and phonological processing.

Significance

It is important to understand the way children with CIs develop PP skills, because of the association between PP and reading achievement in hearing children. One obstacle in assessing PP skills in children with hearing loss is that there are no standardized testing instruments. It is important to construct a PP assessment battery that can potentially identify those CI users who are significantly below their peers with respect to their phonological abilities. Subsequently clinicians can use PP test information to identify the strengths and weakness regarding phonological skill development processes. The information derived from this testing could have implications for remediation of speech, language and literacy skills and can guide clinicians and teachers in choosing goals for rehabilitation. Furthermore, if this study determines that a CI can provide enough access to the structure of speech sounds in the spoken language (phonology) we can then use inferential logic to state that for children with profound hearing loss, the CI facilitates the acquisition of PA skills that support word decoding. Furthermore the input from the CI yields an advantage over the input that is provided by HAs for those with profound hearing loss. If I find that PP skills relate to the variance in reading achievement in CI users, this would have implications for treatment. We could expect that remediation of PP should have a subsequent positive effect on the development of reading skills. In turn, it would suggest that it is appropriate and critical to incorporate this information into the training programs for those professionals who are stakeholders in teaching hard-of-hearing and deaf children how to read. This information would help to build a case that speech-language pathology training programs and programs that train teachers of the hard-of-hearing /deaf and aural rehabilitation professionals should include curriculum that deals with the relationship between phonological awareness and reading skill development.

CHAPTER III

DETERMINING WHETHER EARLY SPEECH PERCEPTION AND PRODUCTION SKILLS PREDICT LATER READING ACHIEVEMENT SKILLS

This preliminary study investigates whether there was a predictive relationship between early speech perception and production skills of CI users on future reading achievement skills. I will also use data from this study to determine which speech perception and production measures to use in a contemporaneous analysis of speech perception and production, phonology and reading skills. As stated in Chapter II, recent studies have demonstrated that children with CIs achieve higher reading levels than their counterparts who use hearing aids. Few, however, have examined the underlying factors that contribute to the better reading skills in CI children, such as the relationship between speech perception, speech production and word reading. In children with normal hearing there is a strong, predictive relationship between PA and early reading skills. Thus, we should expect to see that better perception of sounds and words in children with CIs will lead to increased ability to produce speech, followed by better ability to learn the grapheme-to-phoneme relationship needed for word reading. This preliminary study is designed to ascertain whether it is possible to account for the variance in eventual reading skills by looking at early speech perception and speech production skills.

Method

Participants

I used retrospective speech perception and production data from 72 pediatric CI users (32 females, 41 males) at their 48 month post-operative visit, and reading data was collected on average at the 97 month interval (SD 29.30 mos). At time of CI surgery participants were between 14 and 88 months of age with a mean age of 46 mos (SD 18.25

mos). All participants had prelingual, bilateral hearing loss with no other identified cognitive or learning disability, and none of the children had repeated a grade in school. Additionally all participants underwent CI surgery at the University of Iowa Hospitals and clinics. Etiologies of deafness included unknown, nonspecific heredity component, and identified GJBT mutation (Connexin 26), meningitis, Cytomegalovirus, cochlear malformation, Waardenburg Syndrome, Ushers Type 1, and complications from receiving ototoxic drugs. The type of CI Processors used by the participants included: 2 Nucleus 22-channel WSPs, 28 Nucleus MSPs, 12 Nucleus Spectras, 18 Nucleus Sprints and 3 Nucleus 3-Gs. Processing strategies at the 48 month interval included: 3 using Nucleus F0F1F2, 27 using Nucleus MPeak, 12 using Nucleus Speak and 21 using Nucleus ACE strategies. Appendix A contains the demographic data for the participants in the preliminary study. Data for this analysis was collected under the NIH grant (2 P50-DC 00242) from the National Institute of Health and approved by the University of Iowa Institutional Review Board.

Test Measures

Speech Production Measures

I used the Short-Long Sentence Repetition Task (Short-Long) and a Story Retell task as measures of speech production. I followed the procedures described by Tye-Murray, Spencer and Woodworth (1995). Short-Long sentence repetition required the participants to repeat 14 sentences each after hearing an examiner's model, which was presented in speech and sign (e.g., How are you going to get there? Please stop making so much noise). I transcribed each sample using a target transcription to compare with the actual production. A research assistant tallied the transcriptions using a target transcription to yield a *short-long percent phonemes produced correct* score.

For the Story Retell task, the participants listened and watched me as I told a short story based on a four-picture sequence. I presented each story in speech and Signed English and the children repeated the story. For 43 children I recorded the responses on a Panasonic VHS professional/industrial video camera with a Realistic tie-Pin microphone input. In 2000, the video recording equipment was upgraded to a Panasonic AG-1330 ¾-inch videotape system coupled to a Panasonic WV CP234 surveillance camera with a Tamron 69YE zoom lens and a wall mounted microphone that was situated 24 inches from the participant. I collected speech samples from the remaining 20 children using this set-up.

I subsequently transcribed the children's productions. A research assistant scored the accuracy of production using a target transcription. A comparison of the phonemic transcription and the gloss yielded a story retell percent-correct score (i.e., accurate number of phonemes produced in proportion to the number of glossed phonemes). The percent correct measure was the index of mastery of speech sound production (Tye-Murray et al., 1995). Additionally the phonetic transcriptions yielded percent vowels produced correct score and percent consonants produced correct score.

Transcription and Reliability

I made a phonemic gloss for the intended words based on the participant's signed and spoken utterances, in conjunction with the contexts of the stories. Only the initial 100 spoken words were phonemically transcribed in order to approximately equalize sample size from each participant. The mean number of phonemes produced for the sample was 295.75 (SD= 95) with a range of 51-405.

To demonstrate insignificant transcriber bias, inter-judge reliability measures are periodically performed on randomly selected story-retell speech production samples in the NIH data set. The last reliability check was completed in the year 2005 when 12% of total available samples were checked via a re-transcription procedure. Two separate research assistants (transcribers A and B) who were native speaker of American English and were familiar with the speech of children with hearing impairments completed the reliability procedure. We judged the re-transcriptions with regard to point-by-point phoneme accuracy following a training session. In the training sessions speech samples of pediatric CI users who were not participants of this study were used. The average inter-judge agreements for the original transcriptions and the re-transcriptions by Transcribers A and B were 78.58% (S.D. = 7.04%) and 79.05% (S.D. = 8.87%) across the selected samples. The inter-judge agreements for both transcribers were considered to be within the acceptable range as typical inter-judge reliability for phonemic transcription can range from mid-60s to mid-high-90s (Shriberg & Lof, 1991).

Finally, subjective listener ratings were used to measure speech production skills. A set of 10 raters were asked to listen to an audio recording of the child telling two of the stories. The listeners rated how well they were able to understand the story on a scale of 1 to 10. The total score for the Story Retell Listener Rating was tallied, and possible rating totals were between 0 and 100.

Speech Perception Measures

I used data from the following auditory comprehension tests. The Vowel Perception Test which requires the identification of a monosyllabic word from a closed set of four words (e.g., toe, toy, tie, two) varying only in vowel content (place and height). The Consonant Perception Test which requires the identification of the correct letter/word from a set of 10 choices (D, T, P, B, V, Z, C, me, knee, key) varying only in consonant content. The Phonetically Balanced-Kindergarten Word Test (PB-K) Open Set Test. This test requires the identification of a word presented given open set condition. Scores are reported in percent words correct and percent phonemes correct. Finally, the Word Identification by Picture Identification (WIPI) test was administered. This test requires the child to listen to a word and chose the correct word that was presented from a choice of 6 words. The auditory only percent correct score was used for all tests.

Word Reading and Paragraph Understanding Tasks

I used two subtests from the Woodcock Reading Mastery Tests Revised Form (WRMT; Woodcock, 1987). Data from the most recent post-implant follow-up visit (between 48 and 144 months post CI) was used. The average post-implant interval was 89.63 months (SD 30.16 mos). The *Word Reading* subtest consisted of three tasks. First, the child read a word and supplied a word that meant the opposite of the word read. Secondly, the child read a word and supplied a synonym for the word. The final task required the child to read a series of words to complete an analogy (big is to small as sweet is to _______). All tasks continued until the child achieved a ceiling score (5 incorrect responses).

The reading comprehension measure was the *Passage Comprehension Test* from the WRMT. This is a modified cloze procedure that assesses a child's ability to comprehend a short passage that was 2-3 sentences in length. The child had to comprehend the entire passage in order to complete the sentence with the correct word.

The participants answered in sign, voice and sign or voice only. I used the norms provided from the test to convert the raw score to a standard score based on the child's grade in school.

Social-Economic Status (SES)

I collected SES information for each participant. I determined the highest level of education of the mother of each participant using the following scale: 1 = completed grades kindergarten through grade 8, 2 = completed grades 9-12, 3 = graduated from high school, 4 = completed some post high school programming, 5 = completed a 4 year-college degree, 6 = completed a post-graduate college degree.

Challenges of working with a clinical data set

One of the issues of working with a retrospective data set that contains longitudinal, clinical data is that of missing data. Data points can be missing due to a variety of reasons including fatigue of the child, clinician error, and equipment error. Additionally, in this study some missing data can be attributed to protocol changes. For example at a particular point in time a test may not have been a part of the experimental protocol, or alternatively the test was dropped out of the protocol. There are two choices when a data set contains missing data. One can drop the cases where the data set is missing a test or tests, or drop the whole variable if there are enough missing data points within the data set. Missing data can result in biased estimates, and loss of power. A second option that works when the data is missing for random reasons, as described, is to employ statistical methods to alleviate the problems associated with missing data. In this study, I have chosen to use a multiple imputation method, which allowed me to take advantage of the rich data set and the multiple measures and to preserve as much information as possible. The Department of Biostatistics at the University of Iowa assisted in this portion of the study.

The steps used to complete the multiple imputation procedure are listed. First we did an examination of the data sets for each test to see whether they were normally distributed. Second, in three cases, the data from the sets that did not meet this test including, the Listener Rating, the Percent Vowels Produced Correct for the story retell task, and the Vowel Perception Test, and the data were transformed. For the *Listener Rating* task a log transformation was used and a power transformation was used for each of the vowel tests. The third step was to impute new values for the missing data by performing a random sample from the conditional distribution, trimming data to fit limits of 0 and 100. This meant that the new imputed data was contingent upon the relationships between the existing data set, and confined by those relationships.

- $X_1 \mid X_2, X_3, \ldots, X_p$
- $X_2 \mid X_1, X_3, \ldots, X_p$
- $X_3 \mid X_1, X_2, \ldots, X_p$

;

- $X_p \mid X_2, X_3, \ldots, X_{p-1}$

The fourth step in the process was to repeat the third step 1000 times. The first 200 replications were removed to increase stability. Step 5 was to repeat steps 3-4, which resulted in 5 new data sets with full or "complete" data. Step 6 was to perform a regression analysis on each of the 5 "complete" data sets, and step 7, was to combine the information from the 5 regression analysis.

Results

Means for Speech Perception, Production and Reading Tests

Table 1 presents the means and standard deviations for the speech production and perception variables using the data sets without imputation, and with imputation from the 5^{th} trimmed data set presented as the italicized values. The means from both the non-imputed, and the imputed data sets are very close, thus I will report the imputed data set in the narrative. The averages for the % phonemes correct for the Short Long and the Story Retell task were similar, 67.27% and 63.88% respectively. Accuracy of vowels produced was higher (74.12%) than accuracy for consonants produced (58.35%) in the story retell task. The average listener rating was 44.42 where 100 would be the highest possible score.

Variable Name	*Mean*	*SD*	*Minimum*	*Maximum*
Short Long (n=71,*72*)	67.35 *67.27*	21.30 *21.16*	18	99
Story All Phonemes (n=69,*72*)	64.72 *63.88*	24.82 *24.64*	17.13	99
Story Vowels (n=69,*72*)	75.01 *74.12*	21.67 *21.71*	25.21	100
Story Consonants (n=69,*72*)	58.95 *58.35*	27.58 *27.23*	12.02	99.44
Listener Rating (n=29,*72*)	32.93 *44.41*	26.27 *31.16*	25.21	100
Vowel Test (n=70,*72*)	83.91 *83.21*	20.54 *20.93*	10	100
Consonant Test (n=33,*72*)	41.43 *47.31*	25.22 *29.80*	0	92
PBK Phonemes (n=69,*72*)	58.00 *57.74*	29.90 *29.46*	0	96
PBK Words (n=69,*72*)	39.46 *38.51*	30.00 *29.80*	0	95
WIPI (n=46,*72*)	69.98 *63.64*	20.90 *25.84*	22	100

Note: First value is for the non-imputed n, second, italicized value is the imputed n.

Table 1. Speech production and perception performance at 48 month post implant where the numbers in italics are the values for the imputed data set.

Regarding perception scores, the PBK phoneme accuracy (57.74%) was higher than the PBK word accuracy (38.51%). Vowel perception accuracy was the highest, at 83.21%

Table 2 presents the means and standard deviations of the standard scores obtained on *Word Comprehension* and *Passage Comprehension* reading measures. Average standard score for the *Word Comprehension* measure was 93.38, and the average standard score for the *Passage Comprehension* measure was slightly lower, at 88.05.

	Mean	*SD*	*Minimum*	*Maximum*
Word Comprehension (n= 72)	93.38	19.42	46	141
Passage Comprehension (n=72)	88.05	24.02	7	154

Table 2. Word and Passage Comprehension Standard Scores at 48 months post implant.

Correlations between measures

The rest of the results will be based on the imputed speech production and perception data. The intercorrelations between each of the speech production measures and each of the speech perception measures are in table 3, and table 4. The intercorrelations between the speech production and speech perception measures are in table 5, while the intercorrelations between the speech production and reading measures plus the speech perception and the reading measures are in table 6.

All the speech production measures were strongly related to each other. All had Pearson coefficient values above the .73 level (p <.0001). The highest correlation was between the story retell total percent phonemes correct and the story retell percent consonants correct (r = .96, p <.0001). The lowest correlation was between the listener intelligibility rating and the short-long % phonemes produced correct (r = .73, p <.0001).

	Short Long	*Story (All Phonemes)*	*Story Vowels*	*Story Consonants*	*Listener Rating*
Short Long Phonemes	1.0	.83	.74	.85	.73
Story (All Phonemes)		1.0	.93	.96	.80
Story Vowels			1.0	.84	.74
Story Consonants				1.0	.78
Listener Rating					1.0

Note: p<.0001for all values.

Table 3. Correlation matrix of speech production measures.

All the speech perception measures had a Pearson coefficient values above the .55 level. The highest correlation was between the PBK word and PBK phoneme measures at (r = .95, p <.0001).

	Vowels	*Consonants*	*PBK Phonemes*	*PBK Words*	*WIPI*
Vowels	1.0	.59*	.66	.55	.80
Consonants		1.0	.84	.85	.75
PBK Phonemes			1.0	.95	.85
PBK Words				1.0	.89
WIPI					1.0

Note: p<.0001 except * where p=.0021.

Table 4. Correlation matrix of speech perception measures.

All the speech production and speech perception measures are moderately to strongly correlated. Pearson coefficient were lowest between listener rating and vowel perception scores (*r* =.47 *p* = .017), and highest correlation was between consonant perception and phoneme production on the short-long sentence repetition, and PBK phonemes and % consonants produced correctly on the story retell task (*r* = .85, *p* <. 0001).

	Short Long	*Story (All Phonemes)*	*Story Vowels*	*Story Consonants*	*Listener Rating*
Vowels	.63	.54	.43	.56	.47*
Consonants	.85	.77	.70	.78	.57
PBK Phonemes	.82	.83	.77	.85	.80
PBK Words	.83	.81	.74	.83	.80
WIPI	.80	.76	.71	.77	.74

Note: p<.01 for all values except *, where p=.017.

Table 5. Correlation matrix of speech production and speech perception measures

The Pearson correlation coefficients for both the reading measures and the perception and production measures were more variable. The *Word Comprehension* was most closely associated with the listener intelligibility rating, and phoneme production and consonant production accuracy on the story retell task (*r* = .66, *p*<.001, and .51, .51, *p*<.0001) respectively, while *Paragraph Comprehension* was most closely associated with phoneme production accuracy on the short-long sentence repetition task and phonemes correct on the story retell.

	Word Comprehension	*Passage Comprehension*
Short Long	.45**	.63
Story (All Phonemes)	.51	.58
Story Vowels	.42*	.49
Story Consonants	.51	.59
Listener Rating	.66**	.56
Vowel Test	.29⁺	.58
WIPI	.42⁺	.41⁺
Consonant Test	.29	.38
PBK Words	.41	.51
PBK Phonemes	.40	.56

Note: p<.0001 if unmarked; **p<.001;*p<.01; ⁺p<.05.

Table 6. Correlation matrix between reading, speech production and speech perception measures.

Regression Analysis

Tables 7 and 8 provide the results from regression analysis which was used to predict the amount of variance associated with later word reading scores and paragraph reading scores that could be accounted for by the early speech production and perception measures. Additionally, because socio-economic-status (SES) has been demonstrated to be associated with reading outcome in children with CIs and without (Connor et al., 2002) I used the mother's education level as an SES measure in this model in order to account the amount of variance accounted for by SES.

For the dependent variable *Word Reading* the independent variables entered into the regression analysis included SES, Short Long (% phonemes produced correct), Story Retell (% phonemes produced correct), Vowel Test, Consonant Test, WIPI. For the entire model, four independent variables accounted for 59% of the variance, including Short Long, Story Retell, Consonant Test, and WIPI.

Source	*Beta*	*p<*
Short Long	2.62	.02
Story Retell	2.06	.05
WIPI	3.75	.0005
Consonant Test	-5.06	.0002
SES	-1.10	.31
Vowel Test	-1.65	.14

Note: r-squared for model was .59.

Table 7: Regression results for *Word Reading*

For the dependent variable *Passage Comprehension* the independent variables entered into the regression analysis included SES, Short Long (% phonemes produced correct), Consonant Test, WIPI, and PBK Words. For the entire model, three independent variables accounted for 62% of the variance, including Short Long, , Consonant Test, and WIPI.

Source	*Beta*	*p<*
Short Long	3.26	.004
WIPI	3.86	.001
Consonant Test	-2.10	.05
PBK Words	-1.83	.10
SES	-1.75	.16

Note: r^2 for model was .62.

Table 8: Regression results for *Passage Comprehension*

Discussion

This preliminary study examined the speech and hearing skills of children with prelingual, profound hearing loss after 4 years of listening experience with a CI and the subsequent relationship to word and paragraph comprehension skills. The rationale for this investigation was that CI users are known to have better reading skills than their peers who use hearing aids (Geers, 2003; Spencer et al., 1997), yet we do not know what accounts for the better reading skills. I hypothesized that the speech production and perception skills after 4 years of CI use would have a positive and predictive relationship to subsequent word and passage comprehension.

I based the hypothesis on what we know about how children with hearing learn to read, and what we know about how children who are hard-of-hearing read. Specifically, in hearing children, there is a predictive relationship between PA and subsequent hearing. For children who are hard-of-hearing, those who have better speech perception and better speech production tend to have higher reading skills.

Results of this study replicated earlier studies of reading skills in CI children in that overall standard reading scores were within the low average range. The mean standard scores on the word and passage comprehension assessments were 93 and 88, respectively. Spencer (et. al 2003) reported mean standard-scores of 90.13 on the same passage comprehension measure for 16 prelingually deaf children who had almost 6 years of CI experience. Again the reading scores for CI users are higher than what is typically seen in children with profound hearing loss (Allen, 1986; DiFrancesca, 1972; Traxler, 2000).

The results of this study also indicated that there was a large range in speech perception and speech production skills four years after CI use. Speech perception scores ranged from 0-100%; on average the children perceived vowels with 83% accuracy, consonants with 41% accuracy and words in an open-set condition with 40% accuracy and in a closed-set condition with 70% accuracy. Recall that typically, children with profound hearing loss achieve below 20% accuracy on most such testing. Similarly, speech production scores ranged from 17-99% of words produced correctly, mirroring speech perception trends. On average, after 48 months of experience, the children with CIs were producing 75% of their vowels and 60% of their consonants accurately, with whole-word production accuracy at 65%. Again these production scores are much higher than those scores typically seen in children with profound hearing loss who average about 20% of their words produced accurately (Smith, 1975).

The correlation and the regression analysis supported my hypothesis. Both speech production and perception skills of 72 children after 48 months of CI use had a relatively strong correlation with later word and passage comprehension. Additionally the regression analysis revealed that the for eventual *Word Comprehension* 59% of that eventual variance was accounted for by speech production and speech perception skills at 48 months post implantation. For *Passage Comprehension,* 62% of the variance was accounted for by speech production and speech perception skills at 48 months post implantation. The contribution of speech and listening to reading for these CI children supports the notion of Leybaert and Alegria (1995) (see pp 39-40 of this document) that speech intelligibility may be a measure of the "mental model" of speech, and a measure of phonological skills. Additionally, these results support the findings of Raitano, Pennington, Tunick, Boada and Shriberg (2004) who found that children with normal hearing who have better articulation have better reading skills. The fact that speech production skills 48 months post receipt of a CI predicts later reading proficiency, suggests that there is a link between how children with CIs map the acoustic signal onto phonological representations. This link is likely related to speech articulation. The results of this preliminary study set the stage for the subsequent study. The data suggest that individual differences in hearing and phonological skills predict later individual differences in reading. We can conclude that the children with CIs have access to sound, which help to build their speech production skills. These early listening and speaking skills play through later phonological processing skills. In turn, the phonological skills support language skill development, which help to produce better readers. Given the present findings, I predict that if I evaluate phonological skills concurrently with reading performance, I should find that phonology will also be strongly related to reading achievement. I also predict that phonological processing holds the same relationship to reading performance in CI children as it does in normal, reading-level-matched readers.

CHAPTER IV

EXAMINING THE PHONOLOGICAL SKILLS IN CHILDREN WITH NORMAL HEARING AND THOSE WHO USE COCHLEAR IMPLANTS

I designed this study to answer the second through fourth questions of the project. Having established that listening and speech proficiency was related to eventual reading skills, I aimed to look at the finer-grained skills of phonological processing in this study. The goal of the second question was to establish a series of tasks to measure the phonological awareness and phonological processing skills of CI users. The third question was to determine the range of phonological awareness skills in children with more than 4 years of CI experience, and to compare these skills with their hearing peers. Finally, I wanted to determine the relationship between current speech perception, speech production, phonological processing, word and paragraph comprehension reading skills in children with more than 4 years of CI experience.

Method

Participants

Social-Economic Status (SES)

I collected SES information for each participant using the same procedure described on page 53 for the preliminary study.

Cochlear Implant Users

The children with CIs met the following criteria: they had prelingual, bilateral hearing loss with no other identified cognitive or learning disability, they received a CI at the University of Iowa Hospital and Clinics before the age of seven, they had at least 3 years of cochlear implant experience when examined, and they were under the age of 18. I invited participants to take part in this study during their annual CI follow-up, and I paid them $15.00 for their participation.

In total, 29 CI users participated. The average age at testing was 11 years 9 months (SD= 3 yrs 6 mos) with an age range between 7 years 2 months and 17 years 8 months. The average age of implantation was 3 years 7 months (SD 2 yrs 5 mos) with an age range of 1 year 6 months to 10 years 8 months. Etiologies of deafness included non-specified heredity component, identified GJBT mutation (connexin 26); meningitis, Cytomegalovirus (CMV), cochlear malformation, Ushers Type 1, complications from receiving ototoxic drugs, and several participants had an unknown etiology. All CI users were educated in public school systems (21 within the state of Iowa, 1 in North Dakota, 1 in Illinois, 2 in Wisconsin and 3 in Missouri). Parental report indicated that 28 participants were educated using a *Total Communication* philosophy. “Total Communication” (TC) is a philosophy of communication that is utilized in educational settings and in home environments, and is not necessarily a communication method (Scouten, 1984). For the purpose of this dissertation, “Total Communication” will indicate that the educational programs employed “the combined use of aural, manual and oral modalities in communicating with and teaching hearing impaired individuals” (Garretson, 1976). One child used an Auditory-Verbal approach to aural habilitation, but was educated in a mainstream public school setting where the educators were using TC.

All participants underwent CI surgery at the University of Iowa Hospitals and Clinics. The type of CI Processors used by the participants included 2 Nucleus 22-channel Spectras, 9 Nucleus 22 Sprints, 5 Nucleus 22 Esprit, and 12 Nucleus 3Gs. Processing strategies included: 22 Nucleus ACE strategies, 1 MPeak Strategy and 6 Speak strategies. Demographic information for the CI participants is in Appendix B.

Normal Hearing Controls

I recruited the children with normal hearing from two Area Education Agencies (AEAs) within Iowa, including the Grant Wood AEA and the Mississippi Bend AEA. Participants met the following criteria. They had no known hearing loss, as noted by passing a hearing screening by their local AEA. They had no identified cognitive or learning disabilities as per parent report, and they had not repeated a grade. I paid all participants $15.00 for their participation. Demographic information for the normal-hearing children is in Appendix C.

In total, I tested 32 children with normal hearing (NH). I matched twenty-nine hearing participants with the CI users according to the SES measure of mother's education and to their word-reading grade-levels. A t-test revealed no significant difference in the SES measure between the CI group (M = 4.24, SD =.95), and the hearing group (M = 4.41, SD = 1.05), t (28) = -.65, p = .52). There was no significant word comprehension grade equivalency difference between the CI group (M = 5.21, SD = 4.01) and the hearing group (M = 5.15, SD = 4.01), t (28) = .06, p = .95). The average age of the NH users was nearly two years younger than the CI users, and was 9 years 7 months (SD= 2 yrs 8 mos) with an age range between 6 years 2 months and 17 years 9 months. I tested all participants individually, in a quiet room.

Test Measures

Phonological Processing Tasks

I will characterize the PP tests according to the specific component each test is designed to measure, including Phonological Awareness, Phonological Memory and

Rapid Naming. I used the Comprehensive Test of Phonological Processing (CTOPP) (Wagner, Torgesen, & Rashotte, 2001) and several other tasks to achieve this goal. The CTOPP was developed for the purposes of identifying individuals between the ages of 5 and 25 years who were significantly below their peers with respect to their phonological abilities and to identify the strengths and weakness among developed phonological processes. The CTOPP was designed for normal hearing children and took about 30 minutes to administer. It had 6 subtests where two tested PA skills--*Elision*, and *Blending Words*. Two subtests are considered tests of Phonological Memory, *Memory for Digits*, and *Non-word Repetition* and two that are considered tests of Rapid Naming, including *Rapid Digit Naming* and *Rapid Number Naming*. I will describe the subtests in the section devoted to each subcategory of PP.

Tasks to Assess Phonological Awareness

The *Elision* subtest of the CTOPP required the child to listen to the examiner and delete a sound from the stimulus word. I scored the child's response as either correct or incorrect. I used the raw score to derive a standard score, and a grade equivalency score.

The *Blending Words* subtest of the CTOPP required the child to listen to stimuli presented on an audio file of a compact disk played through a personal computer. The protocol involved a cue sentence, "What words do these sounds make?" followed by the test item "can dee." The child was then supposed to put the word together and say "candy." I scored the responses as either correct or incorrect. I again used the raw score to derive a standard score and grade equivalency score.

I administered a rhyme test that I adapted from (James et al., 2005). This task contained 24 trials that were presented on a personal computer and *E-Run software (E-Prime, 2005)*. Each trial was composed of four photos presented on the computer screen (a cue, a target, and two distracters). The choices for the cues contained a target (which rhymed with the cue item) and two distracters that were chosen to have either a semantic relationship or a phonological relationship with the cue. For example, the cue *hair* had the target *pear,* with a distracter of *bow* (semantically related) and *hill*. Alternatively, the cue *wall* had the target *ball,* with the distractor of *tie* and *wig* (which started with the same phoneme). Half of the targets were either orthographically congruent to the cue (sock, clock) and half of the target were orthographically incongruent to the cue (fruit, boot). James et al., (2005) designed this type of manipulation to allow for error analysis to help determine whether familiarity with the orthography of the word influenced accuracy. Appendix D contains a list of the stimuli for this task, while figure 3 is an example of the computer screen of the cue and the targets. The cue was the photo on the top of the computer screen. The target and the two distracters were the three photos just under the cue photo. All the photos remained on the computer display. The examiner named each picture on the screen and the child was to pick the photo that rhymed with the cue photo.

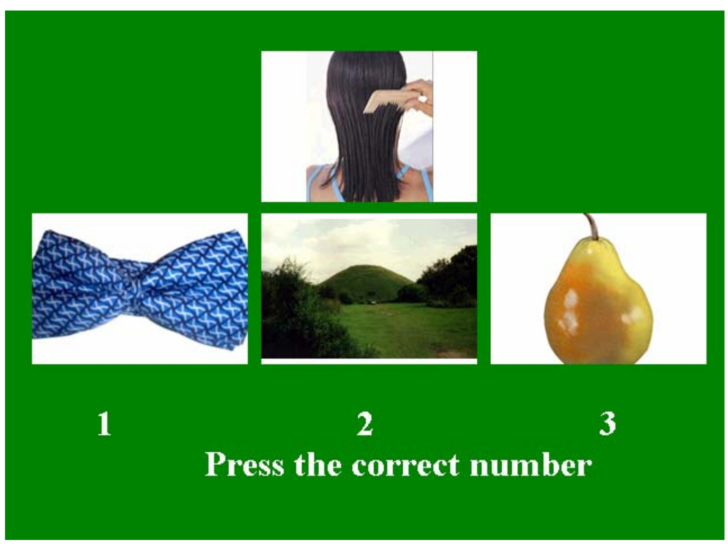

Figure 3. The computer-monitor display of an item from the Rhyme Task.

The examiner entered the number that corresponded with the name of the photo the child picked. If a child missed more than 10 percent of the items (3 or more) I performed a vocabulary verification procedure. For this procedure, I asked the child to identify the picture that represented a missed vocabulary item from a field of three. All 10 CI-children performed the verification procedure with 100% accuracy, and all 3 of the NH children performed the verification procedure with 100% accuracy.

Tasks to Measure Phonologic Memory

All participants completed two versions of the digit repetition task. The first was the *Memory for Digits* subtest of the CTOPP. I presented the stimuli presented using the audio files of the compact disk provided by the test designers played through a personal computer and external speakers. I scored the responses as per the test directions; the item was correct if the child repeated all digits correctly in order.

I administered a second digit task, *Digit Recall.* This task simultaneously presented both an auditory and visual digit stimuli. The task was an adaptive procedure presented via a personal computer and *E-Run* software (E-Prime, 2005). The audio file for each single digit (1-9) nine was pulled from the CTOPP CD and stored as separate files extracted by *Adobe Audition version 1.5* software (AdobeAudition, 2004). The audio file for each digit was randomly pulled, and paired with a visual presentation of the same digit. The combined visual and auditory stimuli were simultaneously presented via a personal computer. Three digits were presented, on at a time on the computer screen (e.g. 6 5 1) paired with the spoken words for each digit. The computer screen then went blank and the child was asked to enter the three digits in the correct order and press the enter key. The E-prime program presented blocks of digits in an adaptive procedure, such that the child had to achieve a criteria of two of the four correct repetitions at each digit level (series of 3, series of 4 series of 5) before the program advanced to the next series level. For example, once the participant was successful with 2 out of 4 sets of three digits, the program would advance to presentations of 4 digits, and so on. If the participant was unable to achieve 2 accurate trials at a particular level, the program would adapt to the previous level, and terminated when the participant could not achieve the criterion 2 repetitions at a series level. The program recorded the total number of correct repetitions for this task.

The final auditory memory task was the *Non-word Repetition* subtest of the CTOPP. The protocol involved a cue, "Say…" followed by the test item "jup." The child was then supposed to put repeat the non-word. Responses were either scored as correct or incorrect. I again used the raw score to derive a standard score and grade equivalency.

Tasks to measure Rapid Naming

Two subtests from the CTOPP were administered, including *Rapid Letter Naming* and *Rapid Number Naming*. I asked the child to look at a block of letters or numbers on a page. I asked the child to say the names of the letters or numbers as fast as possible. I used a stopwatch to time how long it took the child to name the whole block of letters or the whole block of numbers. There were two blocks each of the letters and numbers. The child's raw score was the total time it took to name two blocks of letters, and two blocks of numbers. I used the raw score to compute a standard score and an age equivalency.

Administration Issues

Two tasks from the CTOPP (*Blending Words* and *Non-word Repetition*) required the participants to listen to a pre-recorded CD, and then make an oral response. This presented a particular challenge to validity.

Auditory-only presentation for the children might not be a valid measure of phonological processing for the children with CIs. I hypothesized that children who hear with CIs might require auditory *and* visual input of stimuli. In order to rule out that an incorrect response was due to a lack of the phonological processing skill, rather than an inability to hear or receive the stimuli, I used the following modifications for the children who used CIs. At the beginning of the test session, I administered the items for the *Blending Words* subtest as whole words. I used a live-voice, open-set auditory-only verification procedure. Thus I presented the item (e.g."can-dee") as "candy." I read each item to the child and asked him to identify the word to be sure he or she could indeed hear the word in an open-set condition. Twenty-eight of the 29 children achieved 100% correct on this pretest. There was one child who could not complete this open-set verification for the task. In this case I used spondee words furnished from his speech-perception testing as substitute items for the *Blending Words* subtest. Additionally, note that in order to avoid possible priming effect, I administered this verification task approximately on hour before I administered the *Blending Words* subtest, and kept the children busy completing all other testing in the meantime.

Secondly, if a child missed an item on the standard administration of the *Blending Words* or the *Non-word Repetition* subtests, I re-administered those items at the end of the test session audio-visual live-voice format. I thus derived two scores for these two subtests. One score based on auditory-only presentation, and the other based on auditory-visual presentation.

For children with normal hearing I administered all CTOPP subtests according to the test instructions. I repeated missed items on the *Blending Words* and the *Non-word Repetition* subtests after I completed the entire test battery, in order to maximize the time between the two administration conditions. I used the live-voice procedure described above to collect this score.

Nonverbal Reasoning Tasks

In order to address the question of whether any results were an artifact related to the child's intelligence level, the children completed two subtests (nonverbal memory and block design) from the Universal Nonverbal Intelligence Task (UNIT) to yield a brief measure of nonverbal reasoning skills. I recorded the test scores in terms of standard score, in order to investigate the contribution of intelligence on the variability of results.

Reading Skills

I used the *Word Attack, Word Comprehension* and the *Passage Comprehension* subtests from the Woodcock Reading Mastery Tests Revised Form (WRMT; Woodcock, 1987), to measure reading skills. The *Word Attack* subtest assesses a child's ability to pronounce orthographic strings. This subtest required the child to read a pseudoword. If the child pronounced the word correctly, credit was given. Raw scores were then translated into standard scores. I used the norms provided from the test to convert the raw score to a standard score based on the child's grade in school.

I administered the *Word Comprehension* and the *Passage Comprehension* subtests according to the description outlined in the preliminary study on page 52.

Finally, I administered a *regular/irregular* word reading task (Castles and Coltheart, 1993), who matched the regular and irregular words on word frequency, grammatical class, and number of letters. The children had to read 25 regular words and 25 irregular words aloud. I recorded whether the child pronounced each word correctly to derive a total number correct for each list. If a participant read fewer irregular words correctly than regular words, this indicated that the child was not as good at using the lexical procedure to read words. Thus reading an irregular word (e.g. *yacht*), with the pronunciation "yatcht" would indicate the child was using traditional grapheme-to-phoneme conversion rules, and had difficulty retrieving the sound form that was appropriate for a particular word.

Speech Production tasks (CI users only)

I used the Short-Long *percent phonemes percent correct* (as described on pages 49 and 50) to measure speech production skills. This was collected at the same month of follow-up as the phonology testing.

Speech Perception tasks (CI users only)

I used data from the following speech perception tests. The Vowel Perception Test the Consonant Perception Test the Phonetically Balanced-Kindergarten Word Test (PB-K) and the Word Identification by Picture Identification (WIPI) test described on page 51. I collected the data at the same month of follow-up as the phonology testing.

Results

Summary Statistics for the Phonological Processing Tasks

I computed descriptive statistics for each of the phonological processing tasks. I will present the data for each PP component including Phonological Awareness, Phonological Memory and Rapid Naming, and present the data for each group.

Phonological Awareness

Figure 4 presents the mean grade-equivalency scores for the PA tasks, including *Elision*, and *Blending Words* in the auditory-only (A/O) condition and in the auditory-visual (A/V) condition. The CTOPP test provides three types of scores, raw scores, standard scores and grade equivalency scores. Raw scores are simply the number of items correct. Standard scores are norm referenced scores based on the age of the child and the raw score the child achieved. These scores are represented in terms of a mean of 100 and standard deviation of 15. Grade-equivalency scores are independent of the age of the child, and based on the raw score. Grade equivalency scores represent the grade level at which the raw score is most likely in a normative population. The ages of my two groups were disparate, thus I chose to represent the data using grade-equivalency scores, a reflection of absolute ability rather than the standard score, a measure of relative ability among age mates of the child. Raw scores could also have been used as indices of ability, but these are more difficult to interpret relative to achievement expectations among hearing children.

The Rhyme Task was not part of the CTOPP and therefore did not have normative information available. Therefore, the data are presented as mean raw scores where a maximum possible score was 24. Figure 4 reveals that the mean score for the children in the CI group was lower than the mean score for the children in the NH group on all the PA tasks. For the *Elision* task, however there was no significant difference in means: CI group (M = 5.06, SE = .77) and NH group (M = 6.03, SE = .71) t (56) = -.92, p = .37. For the *Rhyme* task, there was a significance difference in means: CI group (M = 21.07, SE = .79), and NH group (M = 23.28, SD = 4.03), t (40.2) = -2.51, p = .02) (Satterthwaite correction for heterogeneity of variance used). Also note that the mean scores on rhyme for both groups reflected accuracy levels that were over 87% on the test.

Effect of AV/AO Conditions in Blending Words

Recall that one of the purposes of this portion of the study was to produce a set of tasks to measure phonological processing skills of CI users that minimized the influence of hearing on performance. The hypothesis was that children with CIs would be able to complete phonological processing tasks using the auditory-only condition. In order to assess whether this was a valid way to measure the skills, I had to determine whether performance was related to decreased phonological processing skills, or to an inability to perceive the stimuli using auditory/only condition.

To examine this issue, I performed a 2 X 2 Split-Plot *ANOVA* of the four mean scores from the *Blending Words* subtests under each presentation condition, A/O and A/V for each group. Results revealed a significant main effects for group, [F(N,56), = 8.34 p = .006] and presentation condition [F(N, 56), = 21.44, p < .0001], but there was no interaction between group and presentation condition [F(N, 56), = .07, p = .80]. In other words, the NH group performed better than the CI group in each presentation condition, but *both* groups did better in the A/V condition. Additionally, the correlation between scores between the task conditions was .75, p<.0001.

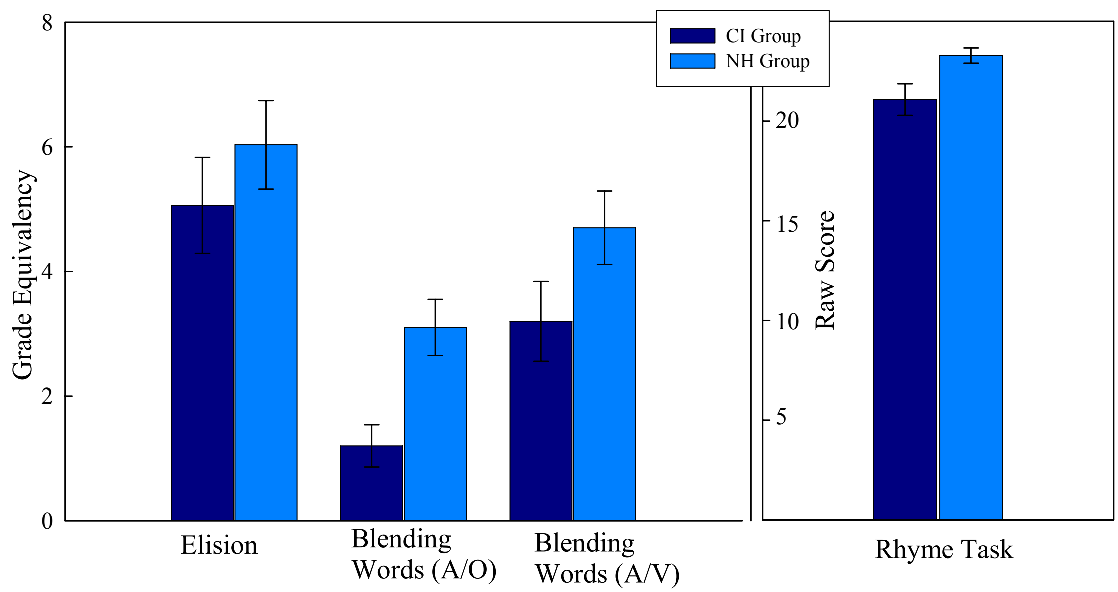

Figure 4. Test data showing cochlear-implant participants' and normal hearing participants' mean performance on the tests of phonological awareness (error bars = 1 SE).

<u>Phonological Memory</u>

Figure 5 presents the mean grade-equivalency scores for the Phonological Memory tasks, *Memory for Digits,* and *Non-word Repetition* in the both the auditory-only (A/O) condition and in the auditory-visual (A/V) condition. For the *Digit Span* task, which was not part of the CTOPP, the data are presented in raw scores. For the *Memory for Digits* task, there was a significant difference in means (M = 1.94, SE = .63) the CI group and for the NH group (M = 4.77, SE = .92) t (56) = -2.51, p = .02. For the *Digit Span* task, there was no significance difference in means (M = 64.72.07, SE = 4.7) for the CI group, and for the NH group (M = 65.52, SE = 4.26), t (56) = -.12, p = .90).

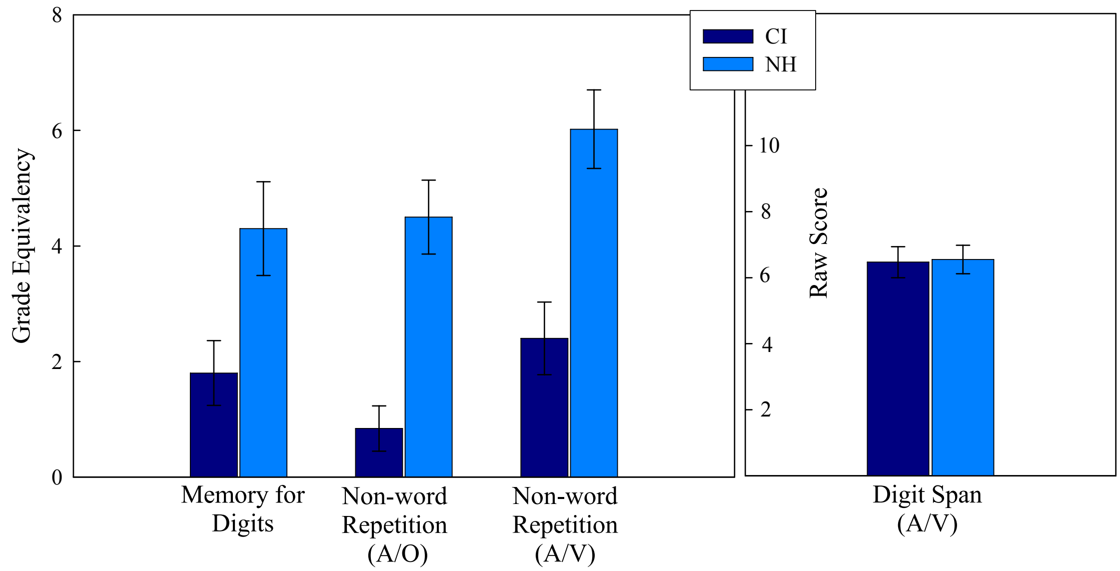

Figure 5. Test data showing cochlear-implant participants' and normal hearing participants' mean performance on the tests of phonological memory (error bars = 1 SE).

Effect of AV/AO Conditions

Similar to Blending, it was necessary to examine the effect of the AV/AO conditions on Non-Word Repetition. I performed 2 X 2 Split-Plot *ANOVA* on scores from the *Non-word Repetition* subtests under each presentation condition, A/O and A/V for each group. Results revealed a significant main effects for group, [F(N, 56),= 23.06 p

<.0001] and presentation condition [*F*(N,55), = 10.45, *p* < .002], but there was no interaction between group and presentation condition [*F*(N,55), = 1.72, *p* = .20]. Again the correlation between performance on task condition was high at .77 *p* <.0001.

Additionally, it is interesting to note that the CI group had a lower mean performance on the *Memory for Digits* task than the NH group. However, there was no group difference on the *Digit Span* task. Recall that the *Digit Span* task included both auditory and visual presentation of the stimuli, where the *Memory for Digits* task only included an auditory presentation of the stimuli.

Rapid Naming

Figure 6 presents the mean grade-equivalency scores for the Rapid Naming tasks, including *Rapid Number Naming*, and *Rapid Letter Naming.* Mean grade-equivalency

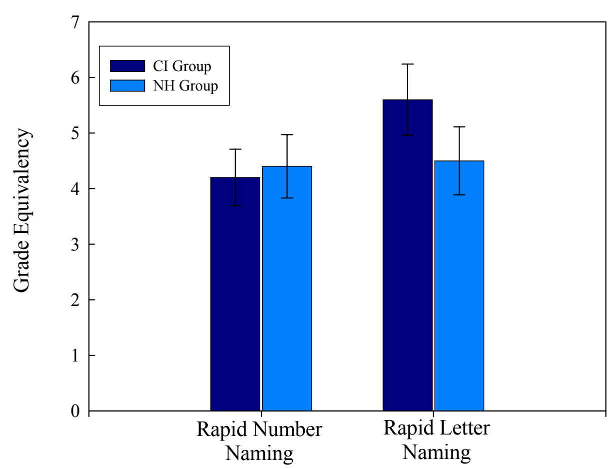

Figure 6. Test data showing cochlear-implant participants' and normal hearing participants' mean performance on the tests of rapid naming (error bars = 1 SE).

score on *Rapid Number Naming* for the CI group was 4.2 (SE = .52) while the mean grade-equivalency score for the NH group was 4.34 (SE = .57). A *t-test* demonstrated that these means were not significantly different [t (56) = -21, p < .84]. For *Rapid Letter Naming,* mean grade equivalency score for the CI group was 5.6 (SE = .61), and the mean grade-equivalency score fore the NH group was 4.5(SE = .51). A *t-test* demonstrated that these means were not significantly different [t (56) = 1.3, p = .20].

Summary: Phonological processing measures and method of choosing measures for regression analysis

The above analysis provided six PP measures. There were four measures of PA (Elision, Blending A/V, Blending A/O, and Rhyme) four measures of PM (Memory for Digits, Non-word Repetition A/V, Non-word Repetition A/O, and Digit Span) and two measures of RN (Digits and Letters). In order to keep the number of hypothesis tests with regard to relationships between the three reading measures and the PP measures it was necessary to reduce the number of PP variables. This reduction of the data set was particularly important for the multiple regression analysis planned given that there were 29 subjects in each group. It is generally thought that one should have not more than 10 subjects per predictor variable (Green, 1991)(Green, 1991) and therefore I needed to reduce the set of variables to three. There are two alternatives for this data reduction. One approach would be to create composite scores for PA, PM, and RN from the individual tests. The other approach would be to select the best exemplar of the measures within each of these PP areas. My preference was for the first of these options, but I also considered the second option.

In order to choose the "best suited" PP tasks to use in the analysis of the relationship between PP and reading, I investigated univariate score distributions and also the bivariate relationship among the different PP measures. Regression analysis is influenced by restriction of variance and therefore I wanted to identify measures that contained ceiling or floor effects in either group that would constrain and confound the analysis. Floor and/or ceiling effects occur when 20% or more of a sample score at the minimum or maximum possible (Holmes & Shea, 1997). Additionally, I looked at the covariance (correlation) between measures within each area of PP to identify measures that were representative of the construct, and group interactions among these. My objective was to select the best measure of PA, PM, and RN based upon its distribution in each group and the covariance of the measure with other measures within the sub-areas of PA, PM, and RN.

First I investigated the distribution of performance on the PP skills across each group of children. I wanted to avoid choosing a task that contained ceiling or a floor effect for either group. Additionally, for reference, the performance distributions for each task for each group are located in Appendix E in scatter plots that show the distribution of the all PP measures across age. Results of this inspection revealed that for the NH group, there was an adequate distribution of scores across tasks except for the Rhyme measure, which showed a clear ceiling effect. For the CI group, however, there were just five tasks that were well-distributed. Figure 7 contains the box plots for all the univariate properties that had acceptable distributions for both the CI and NH groups. These included the PA score from *Elision* and the AV condition of *Blending,* the PM score from *Digit Span* and the AV condition of *Non-word Repetition*, and the RN score from *Letter Naming.* The possibility of combining scores for the PA and the PM measures remained.

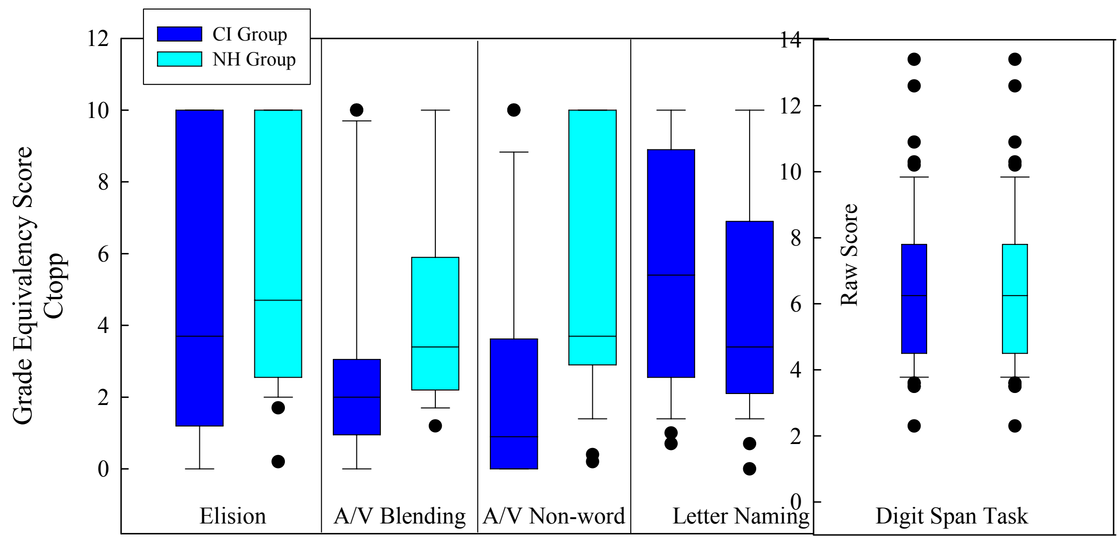

Figure 7 Box plots for all the univariate properties that had acceptable distributions for both the CI and NH groups.

In order to determine if I could combine the two measures within PA and PM, I examined the association of the pairs of measures within each to determine if the relationship between the two measures was similar for each group. I did this to avoid combining measures for each group when the relationship was not the same for each group. I accomplished this by performing a regression between the pairs of measures within PA and PM and testing for group differences of the slopes using the GLM procedure in SAS. First, I converted all the participants' scores on each of the PP tests to a z-score in order that the slopes could reflect a correlation. The results revealed that the slope for the PP measures of *Elision* and AV *Blending* was .37, and .47 for the CI and NH group, respectively. This was found to be significant [$f(2) = 4.79$, $p = .004$.]. The slope for the PP measures of *Digit-Span* and AV *Non-word Repetition* was .44 and .53 respectively, and also found to be significant [$f(2) = 6.11$, $p = .004$.] These findings indicated an interaction between groups, suggesting it would be unwise to combine the measures to formulate a composite score.

Given the results of the aforementioned slope and regression analyses, I decided to use the data reduction method described by the second approach (pp 78) and select the best exemplar of the measures within each of these PP areas. For PA this was *Elision,* for PM, this included *Digit Span* and for RN, this included *Letter Naming.* Table 9 reveals that the correlations between each measure for each group are relatively strong, and that the PP structure for the three measures is the same for both the CI and NH group.

	Digit Span	Rapid Letter Naming
Elision	.71 *.61*	.47 *.66*

Note: The *italicized* values are the correlations for NH children. All values are significant at the p<.05 level.

Table 9. Correlation matrix of phonological processing measures for the CI and NH children.

Nonverbal Reasoning Tasks

Figure 8 reveals that the group mean standard score on the Universal Nonverbal Intelligence Test (UNIT) for the CI children was 103.7 (SE 2.42), and the group mean standard score for the NH children was 110.1 (SE 1.97). A *t-test* demonstrated that these means were significantly different [t (56) = -2.30, p = .03]. While the means are significantly different, the mean standard score for each group was within the average range.

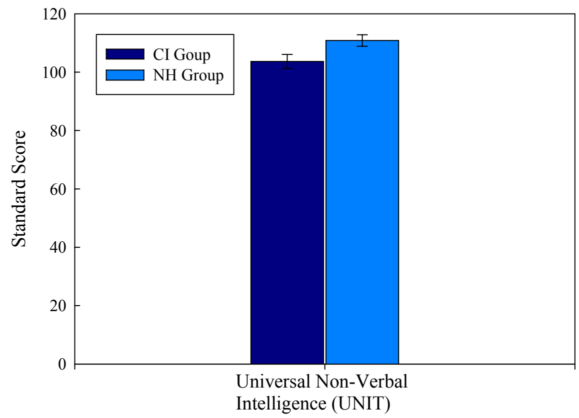

Figure 8. Test data showing cochlear-implant participants' and normal hearing participants' mean performance on the non-verbal reasoning test (UNIT) (error bars = 1 SE).

Group Comparisons for Reading

In this section I will present the results from the *Word Attack, Word Comprehension* and the *Passage Comprehension* subtests from the Woodcock Reading Mastery Tests Revised Form (WRMT), (Woodcock, 1987), using both the standard scores and the grade equivalency scores for a reference. Next I will present the group results from the *regular/irregular* word reading task (Castles and Coltheart, 1993). Finally, I will present the regression analysis that examines the contemporaneous relationship between PP and reading skills for both groups and the correlation relationships between speech production and speech perception for the CI children.

Standard Scores and Grade Equivalency Results: Subtests

Each group of participants' mean standard score and mean grade equivalency score for each reading test is in Figure 9. Examination of the mean standard scores between the groups reveals significant differences for *Word Attack* in the CI group (*M* =

101.31, *SE* = 4.91) and the NH group (*M* = 116.93, *SE* = 2.22), ([*t* (39) = -2.90, *p* = .006]. For *Word Comprehension* in the CI group (*M* = 93.38, *SE* = 3.37) and the NH group (*M* = 107.93, *SE* = 1.65) [*t* (40.7) = -3.88, *p* = .0004], and for *Passage Comprehension* in the CI group (*M* = 91.66, *SE* = 3.65) and in the NH group (*M* = 103.24, *SE* = 1.83) [*t* (41.3) = -2.84, *p* = .007] (Satterthwaite correction for heterogeneity of variance used). Note that in this sample of 29 CI children, the mean *standard scores* on the *Word comprehension and Passage Comprehension* subtests are in concert with the scores seen in the group of 72 CI children, which were 93 and 88 respectively. Thus we can conclude this smaller sample is representative of the larger group of CI children.

The *grade equivalency* performance of the groups however is similar. Recall that I matched the two groups on grade-equivalency performance on the *Word Comprehension* subtest. The grade-performance matching holds for the *Word Attack* subtest, and for *Passage Comprehension*, such that *t*-test results revealed no significant difference in mean grade-equivalency. The *t*-test results are respectively, [*t* (56) = -.08, *p* = .86] [*t* (56) = .06, *p* = .95], [*t* (56) = .58, *p* = .56] for *Word Attack, Word Comprehension* and *Passage Comprehension.* The groups can be different with respect to one score (standard score) and similar on another score (grade equivalency) is illustrative of how the scores take into account the age of the child when tested. Recall that the ages for the two groups are different. The average age for the CI children was 11 yrs 9 mos, while the average age for the NH children was 9 yrs 7 mos, (a difference of about 2 yrs 2 mos).

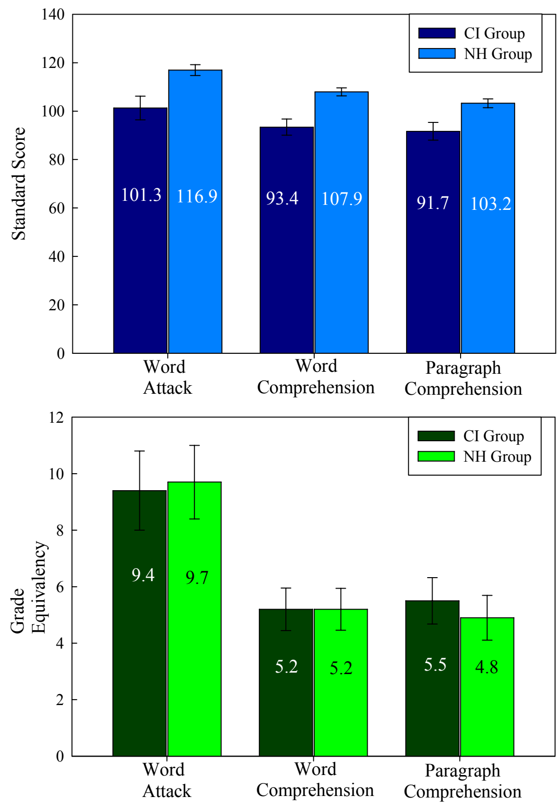

Figure 9. Group means for reading subtests in standard score and grade equivalencies.

Also with regard to standardized scores, 100 is considered average and scores that fall ± 15 points from 100 are within 1 SD from that average. According to this reference, we see that the CI children's readings scores were well within this average range for all reading subtests. Additionally the NH children's scores were within this range as well, with the exception of their average standard score for the *Word Attack* subtest of 116.9 which was nearly two points above the average range. Finally, these results replicate previous findings by previous authors (Geers, 2003; Spencer, Barker, & Tomblin, 2003; Spencer, Tomblin, & Gantz, 1997), that revealed children with prelingual deafness who use CIs tend to achieve reading levels that are comparable with their normal-hearing peers.

Regular/Irregular Word Comprehension Task

Mean group performance for the raw scores for each word list (*Regular words* and *Irregular words)* as well as the difference scores between word-lists is in Figure 10. Results reveal that both groups performed similarly for regular words [t (56) = .58, p = .56], irregular words, [t (56) = .85, p = .40], for the difference score. Both groups were

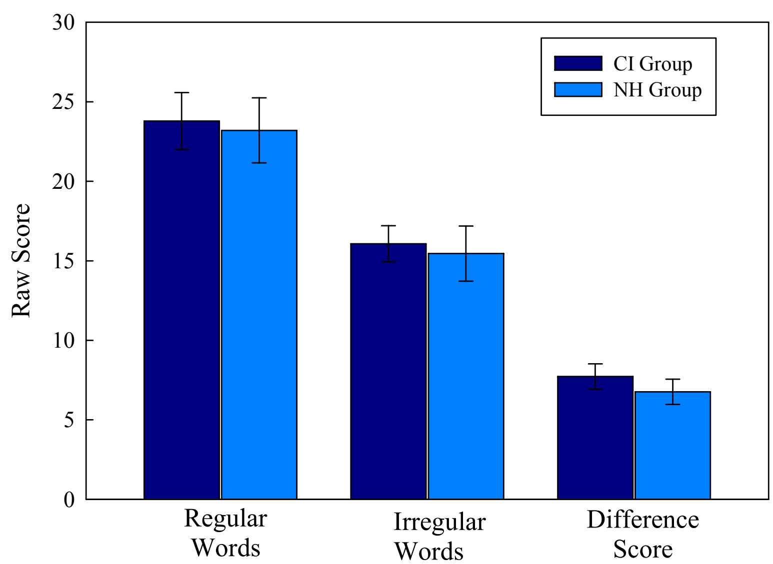

Figure 10. Mean raw scores for the *Regular/Irregular Word* task presented as group comparisons.

more accurate with reading regular words than irregular words. This difference in accuracy between the word types indicates that both groups used traditional grapheme-to-phoneme conversion rules (Castles & Coltheart, 1993).

Contemporaneous Relationship between Speech Production, Perception, PP and Reading Skills for the CI Participants

This final section of results section will present data to answer the fourth question of the study, which was to determine the relationship between current speech perception, speech production, phonological processing, and reading comprehension skills in children with more than 4 years of CI experience. Additionally I wanted to test whether the relationship between PP skills and reading skills was similar between the CI and hearing groups. The hypothesis was that stronger phonological processing would be related to better reading skills in children with CIs and normal hearing. There were insufficient grounds to motivate a hypothesis regarding whether this relationship would differ for the two groups.

<u>Relationship between SES, Non-Verbal Reasoning, and Reading Measures</u>

SES and Non-verbal intelligence could both be associated with both PP and reading and therefore confound the covariate relationship between PP and reading. In order to see if there was a relationship between SES, Non-Verbal Reasoning (*UNIT*), performance and the Reading/PP measures, I ran a Pearson's correlation analysis. Results of the analysis are in Table 10 and reveal that none of the intercorrelations were significant for SES and any of the reading measures for either group. Additionally there were no significant correlations between the *UNIT* and *Word Attack* or the *Unit* and *Word Comprehension*. There was a weakly significant correlation between the *Unit* and *Paragraph Comprehension.*

Reading Subtest	*SES*	*UNIT*
Word Attack	.17 *.02*	.21 *-.07*
Word Comprehension	.29 *-.02*	.28 *-.04*
Passage Comprehension	.13 *-.19*	**.38** ***-.36***

Note: Values in *italics* NH group. Bold values are significant at p< .05.

Table 10. Correlations between SES, NonVerbal Problem Solving, and Reading.

No Phonological Processing measures were significantly correlated with the non-verbal intelligence scores on the UNIT. Several Phonological Processing measures were correlated with SES, and they included *Elison* (r = .39, p=.05), the *Rhyme Task* (r = .44, p=.02), *Non-word Repetition* (r = .41, p=.05), and *Rapid Number Naming* (r = .41, p=.05). Because there was not a significant correlation between SES, UNIT and Reading, the covariance between the SES, UNIT and PP measures cannot be confounded. Thus neither the SES or the UNIT variables were entered as covariates in the subsequent analyses.

Accounting for Variance in Reading Measures

For the *Woodcock Reading* subtests, scores can be reported in standard scores, grade equivalencies or *w-scores.* A w-score is a result of a mathematical transformation of a Rasch-based ability score and is a better representation of absolute ability than grade equivalence scores. A multiple regression using the GLM procedure was used to predict the amount of variance associated with the W-scores on the dependent reading measures of *Word Attack*, *Word Reading* and *Passage Comprehension* that could be accounted for by each of the PP components across Group (CI, NH). This test also allowed for a test of the group by predictor variable interactions in order to determine if the relationship between a predictor variable differed by group. Recall that I used the "best distributed" score from each of the relative elements as outlined above for my explanatory variables. Thus for the Phonological Awareness component, it was *Elision,* for the Phonological Memory component it was *Digit Span*, and for Rapid Naming it was *Rapid Letter Naming*. The results of the analysis are in Table 11 for the dependent measure of *Word Attack*. For the entire model, the three PP measures explained 50% of the variance for Word attack. Most of this was accounted for by the *Elision* measure. There was no interaction between group and test for *Elision* or *Rapid Letter Naming*, but there was a group by test interaction for *Digit Span* [t (1) = -2.12, p = .04]. The slope for the regression line for *Digit Span* and *Word Attack* is steeper for the NH group than for the CI group (see figure 12).

The *Word Comprehension* dependent measure results are in Table 12. For the entire model, the three PP measures explained 75% of the variance. Both the *Elision and Rapid Letter Naming* made significant contributions. There was no interaction between group and test for *Elision and Rapid Letter* Naming, but again there was an interaction between group and test for *Digit Span* [t (1) = -2.43, p = .02], and again the slope for the regression line for *Digit Span* and *Word Attack* is steeper for the NH group than for the CI group (see figure 12).

Model r^2	*Source*	*df*	*Slope Estimate*	*Standard Error*	*f-value*	*p<*
.50						
	PA *Elision*	1	11.23	5.18	19.56	.0001
	PM *Digit Span*	1	3.72	4.53	1.09	.30
	Naming *Rapid Letter*	1	1.64	4.62	3.70	.06
	Elision by Group	1	6.67	6.65	1.0	.32
	Digit Span by Group	1	-14.56	6.86	4.51	.03
	Rapid Letter by Group	1	8.52	6.37	1.79	.19

Table 11: General Linear Model results for PP scores and *Word Attack.*

Model r^2	*Source*	*df*	*Slope Estimate*	*Standard Error*	*f-value*	*p<*
.75						
	PA Elision	1	11.99	1.99	20.47	.0001
	PM Digit Span	1	9.57	4.53	.78	.38
	Naming Rapid Letter	1	8.54	3.81	22.39	.0001
	Elision by Group	1	1.13	5.61	.04	.84
	Digit Span by Group	1	-14.03	5.78	5.89	.02
	Rapid Letter by Group	1	7.40	5.37	1.90	.17

Table 12: General Linear model results for PP and *Word Comprehension.*

Model r^2	*Source*	*df*	*Slope Estimate*	*Standard Error*	*f-value*	*p<*
.43						
	PA *Elision*	1	3.85	7.94	1.71	.20
	PM *Digit Span*	1	14.06	6.94	.81	.37
	Naming *Rapid Letter*	1	3.38	7.09	6.87	.02
	Elision by Group	1	5.51	10.2	.29	.59
	Digit Span by Group	1	-18.73	10.51	3.18	.08
	Rapid Letter by Group	1	17.88	9.75	3.36	.07

Table 13: General Linear Model results for PP and *Passage Comprehension*.

The *Passage Comprehension* dependent measure results are in Table 13. For the entire model the three PP measures explained 43% of the variance. The *Rapid Letter Naming* task accounted for most of this. There was no significant interaction between group and test for any of the tasks.

<u>Examining the relationship of PP and Reading by group</u>

Because I found a significant group interaction for Digit Span with Word Attack and Word Comprehension, I examined the bivariate relationships by groups. This relationship was also performed for the other variables in order to describe these relationships despite the absence of group differences. In order to gain an idea of the relationship of group performance between each of the PP measures on each reading variable, I plotted the regression lines for each group. These regression graphs between each of the three phonological processing measures and the reading measures are in for the CI children and NH children are presented in figures 12-14.

Figure 11 illustrates the relationship between the PA measure of *Elision* and the reading scores from *Word Attack, Word Comprehension* and *Passage Comprehension.* It is evident that for both the CI and NH groups, there is a significant and important relationship between PA and reading, especially for early word decoding and comprehension skills. Figure 12 illustrates the relationship between the Phonological Memory measure of *Digit Span* and the reading scores. Recall that in the regression analysis there was a group interaction between the *Digit Span* and *Word Attack* and *Digit Span* and *Word Comprehension.* The *Digit Span* task was correlated to *Word Attack* (slightly more so for the CI group), strongly correlated to *Word Comprehension* for both groups, and moderately correlated to *Passage Comprehension* for both groups.

Figure 13 presents the results for the PP measure *Letter Naming* and the reading measures. *Letter Naming* was moderately correlated with *Word Attack* for both groups, and strongly correlated with *Word Reading* for both groups. In summary, the results looking at the PP measures and their relationship with reading follows what has been seen in NH children for other studies (Wagner, et al., 1999). Furthermore the three PP constructs (PA, Phonological Memory, and Naming) appear to be structured in the same way for both the CI and the NH children.

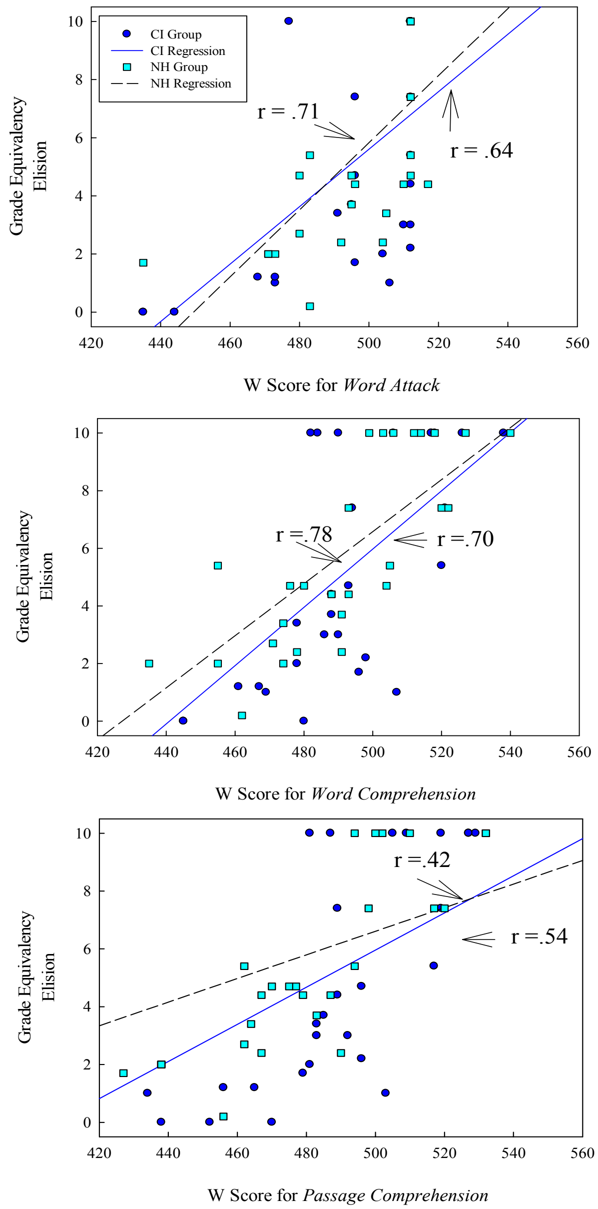

Figure 11. The relationship of PA and reading with regard to *Word Attack*, *Word Comprehension,* and *Passage Comprehension* scores.

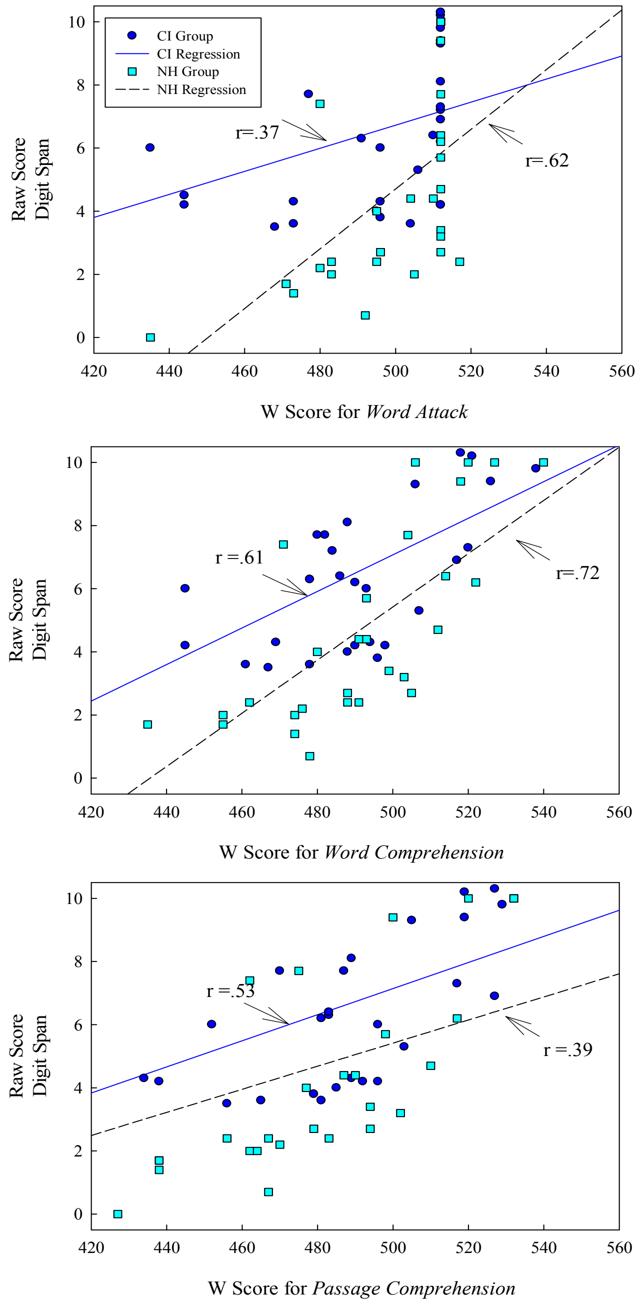

Figure 12. The relationship *Digit Span* and reading with regard to *Word Attack*, *Word Comprehension,* and *Passage Comprehension* scores.

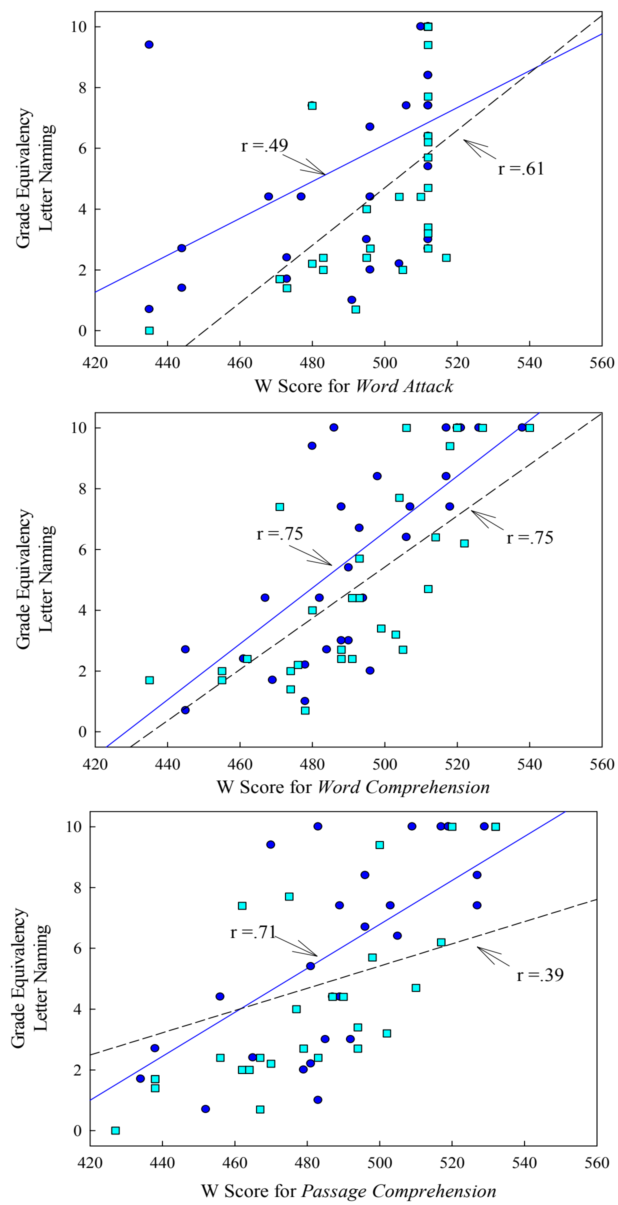

Figure 13. The relationship between *Letter Naming* and reading with regard to *Word Attack*, *Word Comprehension,* and *Passage Comprehension* scores.

The relationship between PP, reading speech production
and perception

The intercorrelations between the speech production, speech perception and reading measures for the CI group are in Table 14. It is of interest to compare the correlations between the present 29 children with the larger group of users at 48 months. Note that the correlations between *Word/Passage Comprehension* and speech perception and production measures tend to follow the same trend as the correlations seen on the same measures taken back at the 48 month follow-up interval for the larger group of CI users (pp 59). Note, however that all means for speech production and perception scores are increased by nearly 20% for each measure from the 48-month interval.

The intercorrelations between the *contemporaneous* speech production, speech perception and the three PP measures are in Table 15. These correlations were significant for nearly all the PA relationships and tended to be moderate. The highest correlations were between the PA score on the *Elision* and the Speech production score of *Short Long* (r = .52 <.001). On the other hand the correlations between speech production, speech perception and the PM and RN tasks, were quite low and not significant.

Additionally, the intercorrelations between the between the *early* speech production, speech perception and the three PP measures are in Table 16. These correlations followed the same trend seen in the contemporaneous correlation matrix. They were moderate and significant between PA and *short long* and *Wipi*. On the other hand, the correlations between speech production, speech perception and the PM were quite low and not significant, but they were moderate between RN (*rapid letter naming*) and *short long, consonants, Wipi* and *PBK phonemes.*

Production/Perception Measure	*Mean(SD)*	*Word Attack*	*Word Comprehension*	*Passage Comprehension*
Short Long	87.5 (16.9)	**.40**	**.44**	**.38**
Vowels	96.3 (8.2)	**.47**	**.41**	**.36**
Consonants	66.1 (20.5)	**.41**	.27	**.15**
PBK Phonemes	80.93 (21.1)	.20	.15	.19
PBK Words	65.1 (22.9)	.28	.20	**.20**
WIPI	85.7 (17.8)	**.43**	**.51**	**.42**

Note: All **bold** values are significant at the p<.05 value.

Table 14. Correlation matrix of reading measures, and speech perception and speech production measures.

	Short Long	*Vowels*	*Consonants*	*WIPI*	*PBK Phonemes*	*PBK words*
Elision	**.52**	**.59**	**.56**	**.49**	**.37**	**.49**
Digit Span	.19	.29	**.52**	.30	-.05	.02
Rapid Letter Naming	.18	.30	.05	.38	-.01	-.02

Note: All bold values are significant at the *p*<.05 level

Table 15. Correlation matrix of phonological processing measures, and *contemporaneous* speech production and speech perception measures.

Finally, the inner correlations between the *contemporaneous* speech production and perception measures and the *early* speech production and perception measures are in Table 17. These correlations are strong and significant for all measures.

	Short Long	*Vowels*	*Consonants*	*Wipi*	*PBK Phonemes*	*PBK words*
Elision	**.37**	.35	.29	**.44**	.10	.09
Digit Span	.09	.19	.17	.09	-.09	.08
Rapid Letter Naming	**.40**	.31	**.45**	**.50**	**.39**	**.42**

Note: All bold values are significant at the $p<.05$ level.

Table 16. Correlation matrix of phonological processing measures, and *early* speech production and speech perception measures.

	Short Long	*Vowels*	*Consonants*	*Wipi*	*PBK Phonemes*	*PBK words*
Short Long	**.82**	**.83**	**.69**	**.80**	**.76**	**.63**
Vowels	**.64**	**.78**	**.79**	**.85**	**.59**	**.59**
Consonants	**.40**	.31*	**.45***	.50	**.42***	**.39***
WIPI	.74	.86	**.72**	**.81**	**.68**	**.56**
PBK Phonemes	.67	.63	**.76**	**.79**	**.77**	**.69**
PBK Words	.74	.69	**.75**	.72	.76	.67

Note: All bold values are significant at the $p<.001$ level, all others are significant at the $p<.01$ level, except * which are significant at $p<.05$.

Table 17. Correlation matrix of between *early* speech perception and production measures and *contemporaneous* speech perception and production measures.

CHAPTER V

DISCUSSION

I completed the present study in two parts, and considered how the early listening and speaking skills of prelingually deaf children with CIs predict their eventual word reading and passage understanding skills. I predicted that early speech and listening skills in CI children would account for eventual variance in reading skills. Secondly, I examined the relationship among concurrent measures of Phonological Processing (PP), word attack, word comprehension and passage comprehension in both children with normal hearing and those using CIs. I predicted that children with CIs would be able to demonstrate the skills needed to complete sound-based phonological processing tasks and these skills (blending, deleting sounds, phonologic memory, naming) would be related to reading. I asked whether the relationship between PP skills and reading was similar in CI children and children with normal hearing. Finally I predicted that there would be a relationship of PP skills to both speech and hearing ability and to word and passage reading skills. These predictions were based on the literature that suggests children using CIs read better than their counterparts who wear hearing aids, and the literature that suggests for hearing children, an intact phonological system provides an important foundation for learning to read. The findings regarding the first study have already been discussed (early speech perception and production was related to later reading) but I will return to these after first discussing the results of the second study that examined the concurrent relationship between PP and reading.

The discussion is organized with regard to the three components of Phonologic Processing (PP) which include Phonologic Awareness (PA), Phonologic Memory (PM) and Rapid Naming (RN). Next, I discuss the relationship between PP and the reading skills of Word Attack, Word Comprehension, and Passage Comprehension. After that I give clinical implications and directions for future studies. Finally, I provide a brief discussion that highlights the relationship between listening, speaking, phonological processes and reading.

Summary and Implications of Findings

The second question of the project asked whether it was possible to establish a series of tasks to measure the PP skills of CI users, and what the range of the PP skills would be. I will briefly review each measure of PP in order to address these questions.

Phonological Processing: Task Selection, Development, and Theoretical Implications

I found that certain tasks were better suited for evaluating the PP skills in the children with CIs. One of the ways I chose the "best suited" tasks to use in the general model was to look at the distribution of performance across each group of children. In this section, I will briefly review all the PA tasks, including the ones that I did not include in the regression analysis, in order to discuss the theoretical implications of the results.

Phonologic Awareness

One of the easiest PA tasks for hearing children is *rhyming* (Adams, 1990). Hearing children usually begin to show rhyme awareness in the preschool years and have mastered the concept by first grade (Bradley & Bryant, 1991). In the current study, the majority of the CI children could perform the *rhyme task* with over 85% accuracy. Unlike hearing children, however, there were some CI participants in this study who did not achieve ceiling performance even by age 10 years. The present group of CI children did perform better than the group of younger CI children in the study by James et al., (2005). In that study, twenty CI children achieved a mean accuracy level of 56% and then 77% at mean age levels of 8 years 5 months and 9 years 5 months, respectively.

Those children also had, on average, fewer years of CI experience (4 and 5 years, respectively). Taken together, the findings of this study and the James, et al., (2005) study indicate that awareness of syllables and rhyme emerges gradually over time for most, but not all of the CI children.

For the *blending words* task, the CI children performed nearly uniformly at the early-elementary level (up to third grade equivalencies) regardless of their chronological ages and regardless of presentation condition (A/O, A/V). In contrast, the NH children tended to achieve ceiling performance by age 10 years. This finding indicates that the NH children master the *blending* skill by age 10 years, but that the CI children are still developing this skill throughout their elementary years and even into their teen years. Recall that in the continuum of difficulty of PA skills, *blending* is considered to be an intermediate skill (see page 9 and 10 for summary of Adams 1990; and Stahl and Murray, 1994).

The CI children fared much better on the *elision* task, considered to be one of the harder PA skills (see page 9 and 10). Both the NH and the CI children tended to display a well-distributed performance pattern across age ranges. Even so, there was not a pattern of uniform mastery on *elision* by a specific age for the CI children. Where the NH children demonstrated evidence of mastery on the task by age 10 years, there were approximately 6 children in the CI group who performed below the 4th grade level after age 10 years. The implications of these findings reveal that while there is certainly evidence that children with CIs do develop PA skills, their performance is characterized by a longer, more protracted learning phase before mastery is achieved than their NH counterparts. Interestingly, the CI children performed fairly well as a group on the harder task of *Elision*. One explanation for this result could be attributed to the nature of the task, which requires the child to first say the word, (e.g. "bold"). Then the child is to repeat the word without saying a part of the word (e.g. "b") as in "Say "bold" without the "b." The first task of saying the word may serve two purposes. In the case of the children with a CI the examiner can verify that the child hears the correct word. Also for the children with CIs the child produces the movements for the whole word. This act of articulating the whole word could facilitate awareness of the "mental model" of the parts of the word (Leybaert and Algeria, 1995), which for the CI children could especially facilitate assessing PA, because it assures the child has the correct word in mind.

In summary, the CI children performed best on rhyming, with a near ceiling-effect. In contrast, they had a near floor-effect for the *blending task*, but the performance on the *elision task* was well-distributed. The performance differences within the CI group across the tasks could indicate that rhyming is a precursor skill to reading, and that *elision* tasks are well-suited for assessing PA skills in children with CIs who are at this age and developmental level.

PA and Reading

The results also revealed that, for both the CI and NH groups, there was a significant and strong relationship between the PA measure of *Elision* and reading, especially for early word decoding and comprehension skills. This finding, taken together with the results of the preliminary study drives home the notion that for children with profound hearing loss who receive CIs, access to sound makes an important contribution to the reading process. This correlation also highlights that the relationship between PA and reading is similar for both CI and NH children, albeit protracted for children with CIs.

There is evidence that some children in both the CI and NH groups demonstrate an exception to the pattern that PA is associated with reading, however. For example, some children who scored at a relatively low grade-equivalency level for the *Elision* task had relatively better w-scores for reading. Furthermore because there was inconsistency in performance across all the PA tasks of rhyming, blending and elision, it is likely that PA is a necessary, but not sufficient skill for reading. I also showed that the PA skill of *Elision* was more highly correlated to *Word Attack* and *Word Comprehension* than it was to *Passage Comprehension* for both groups of children. This indicated that both groups relied more on the sound-based coding for the word level, but that other factors such as world knowledge and higher level language skills are playing a role in comprehension of passages. It is not clear from the current results, however, whether the PA skills tested here are precursors to reading or a *result* of reading for either the CI or NH children.

Phonological Memory

On the Phonological Memory subtests, I frequently noted differences between the CI and NH groups with regard to performance on most tasks. There were significant differences in group performance on the *non-word repetition* task for both the A/O and A/V modalities. On the *non-word repetition* task, the CI children had a nearly uniform performance at the early-elementary level (kindergarten to second grade equivalencies) regardless of their age in the A/O presentation condition, with slightly better performance (up to fourth grade) in the A/V condition. In contrast, the NH children tended to achieve ceiling performance by age 10 years regardless of presentation condition (i.e., A/O or A/V). On the *Digit Repetition* task, there were significant differences in performance between groups with higher mean scores for the NH group. The results are in concert with the findings of others, in that children with CIs tend to display shorter working memory for verbal and spatial patterns than their hearing counterparts (Burkholder & Pisoni, 2003; Cleary, Pisoni, and Geers, 2001).

For the *Digit Span* task, the two groups performed similarly and the distribution of scores was uniform for both groups. The *Digit Span* task utilized visual presentations of digits on a computer monitor, paired with auditory presentations. Additionally, the response modality was the computer keyboard. The distributed results and the similarities seen between groups on the *Digit Span task*, tested using the described methodology in this study, are in contrast with the above-mentioned studies that found significant short-term memory differences between children with CIs and with normal hearing. Given this, I suggest that the visual/auditory/key-pad testing method for digit-span for CI children is more indicative of their true short-term memory skills, and these results reveal that there may not be memory differences between the CI and NH groups. This method appears to be less susceptible to the effects of the distorted auditory signal. In addition, the use of the key-pad for responding, eschew the effects of slowed or distorted speech production. These results also support the finding by Burkholder, Pisoni and Svirsky (2005) that for adults with *normal* hearing, digit span was reduced if they were given a degraded auditory signal (an 8-channel frequency-shifted acoustic simulation of a CI). The authors attributed the performance decline to misidentification or to an incorrect encoding of digits, due to the degraded signal, rather than to ineffective subvocalization rehearsal or serial scanning of phonological representations in the short-term memory task. Given this logic, the same precautions should be made in testing the memory skills in prelingually deaf children who use CIs, who would be even more likely to have performance declines related to listening and speaking. Unlike normal hearing adults who have well-developed audition, children with CIs have never had hearing, nor do they have the articulation skills of adults. Thus testing memory using vision, sound and keyboarding appears to be a more accurate method.

Phonological Memory and Reading

As mentioned above in the results, PM in the form of Digit Span was correlated with all subtests of reading for both groups. Additionally there was a group by task interaction on PM for *Word Attack* and for *Word Comprehension*. *Digit Span* was associated with performance on *Word Attack* (but more so for the NH group than for the CI group). PM was strongly correlated with *Word Comprehension* for both groups, but again the relationship was significantly stronger for the NH group than the CI group. Finally, PM was correlated with *Passage Comprehension* for both groups.

Phonological memory is an important skill used for learning new, spoken and written words (Gathercole & Baddeley, 1990). A deficit in phonological memory could constrain the ability to learn new written and spoken words. Conversely, superior phonological memory is associated with better learning vocabulary learning (Service, 1992; Service & Kohonen, 1995) and with learning the phonological characteristics of words (Gathercole & Baddeley, 1990). Gathercole, Service, Hitch, Adams and Martin (1999) completed two studies that documented the association between phonological memory and vocabulary in children with NH. They found that this association was strong throughout childhood and suggested that PM plays a crucial role in learning vocabulary by supporting the long-term phonological learning of new sound patterns. Pennington, Van Orden, Kirson and Haith (1991) speak to the causal relation between verbal short-term-memory (STM) problems and reading disorders. They make the case that typically the STM problems are present before reading begins, and state that does not appear to be a consequence of dyslexia, but something that contributes to dyslexia. In the case of the broader PP skill of Phonological Memory, it would seem more reasonable to assume that length of digit span is *not a result* of having reading experience. Rather the directionality of this relationship may be that it *facilitates* word and vocabulary learning, thus indirectly facilitating word and passage comprehension.

Rapid Naming

Recall that naming speed has been found to be predictive of early reading skill because it is thought to be a measure of the efficiency of retrieving phonological codes associated with phonemes, parts of words, or entire words (Shankweiler & Crain, 1986; Share, 1995; Torgesen & Burgess, 1998). There were two tasks that assessed naming speed in this project, naming numbers and naming letters. For *Number Naming*, the CI group demonstrated a lot of variability in their performances, with a very unequal distribution of scores. The CI group never did evidence mastery of the skill, as evidenced by ceiling performance, even after age 12 years. In contrast, I found that both groups demonstrated variable and similarly distributed performances on *Letter Naming*. Additionally *Letter Naming* was moderately correlated with *Word Attack* for both groups, and strongly correlated with *Word Reading* for both groups. *Letter Naming* was strongly correlated to *Passage Comprehension* for the CI group and moderately correlated for the NH group and again the strength of this relationship was not found to be significantly different for the two groups.

The discrepancy between the *letter naming* and *number naming* results in the CI group tends to support the idea that they were better at retrieving the sounds or name-codes associated with the letters than for numbers. According to the authors of the

CTOPP, performance with number naming and letter naming is highly correlated in children with normal hearing (Wagner et al., 1999, p.100). In this study, the correlation between number-naming and letter-naming for the NH children was high, r = .87, $p < .0001$, yet for the CI children the correlation was negative and not significant, $r = -.25$, $p > .05$. This indicates that for the CI children the act of vocalizing the names of numbers takes more time than the act of vocalizing the names of letters. Again, it is difficult to tell for certain whether letter naming proficiency is a *precursor* to reading, or *result* of reading, yet for some reason it is associated with reading in a way that is more closely related than is the act of naming numbers. The CI children in this study were familiar with sign language. As a result, it is likely that they had a lot of experience as preschoolers with listening to the names of letters as they were simultaneously signed and spoken during finger-spelling and letter-learning activities. This could mean that letter names are highly salient for the children, where the names of numbers are not. The task of letter-naming, therefore is evidence of a very well-learned phonological representations, where the task of number-naming is not.

Reading Words

The results for *Word Attack*, plus*, Regular and Irregular* word reading scores reveal a similar pattern of performance for both the children with NH and CIs. First, both groups performed very well on the *Word Attack* subtest, and some children in both groups achieved ceiling performance. Secondly the finding that both the NH and CI group had more difficulty reading irregular than regular words suggests that at this point in development, both groups are not skilled as using the lexical procedure for word reading. Recall that the lexical procedure involves retrieving, from the mental lexicon, the phonological form appropriate to the printed word (Castles and Coltheart 1993). Thus the finding that both groups tended to pronounce irregular words incorrectly (e.g., “island”) pronounced as IS-land, illustrates that each group had difficulty pairing the printed, irregular word with the known *sound* of the entire word. In other words, the finding indicates the children were using traditional grapheme-to-phoneme conversion rules to decode the words, rather than relying on their knowledge of how the words sound.

The multiple regression demonstrated that 50% of the variance in *Word Attack* skills for both the CI and NH children was explained by the three phonological processing skills (i.e., PA, PM, and RN) and the interaction between these skills and the group. This relationship suggests that phonology indeed plays a role in phonological decoding for both groups. However, the data also suggest that the children with CIs differ from hearing children with respect to the extent to which PM is associated with word attack. For the children with CIs, PA was highly correlated with decoding performance (*Word Attack)* in the present study, this contradicts literature that suggests children with profound hearing loss tend to use whole-word recognition strategies as opposed to grapheme-to-phoneme conversion rules (Merrills et al., 1994; Treiman & Hirsh-Pasek, 1983; Wauters et al., 2001). Indeed, these CI children in the present study *do* appear to be relying on decoding and the relationship between graphemes to phonemes as indicated by the multiple regression analysis.

Comprehending Words

Because the two groups were matched on their ability to comprehend words, I will reiterate that in order to achieve this matching, I had to find NH children that were, on average, approximately 2 years younger than the CI group. While I have found many similarities in performance between the two groups, this age difference emphasizes that the performance of the children with CIs are somewhat behind the performance of their NH peers. With this in mind, however, the overall standard-scores of the CI group did fall within the low-average range.

The multiple regressions showed that 75% of the variance in *Word Comprehension* skills for both the CI and NH children was explained by phonological processing skills and the interaction of these skills with the group variable. As with *Word Attack*, the contribution of the PP variables was similar for the two groups with the exception of PM, which was less strongly associated with word comprehension in the CI group than in the NH group. The regression results suggest phonological processing skills contributes to comprehending words, and is in concert with Gough and Tunmer's (1986) findings that reading is a product of decoding and semantic comprehension skills. In other words the skills of decoding and comprehension are necessary, but that neither one by itself is sufficient. Additionally each of the component PP skills was very highly correlated with word comprehension, suggesting a shared set of skills between the construct of PP and word comprehension. It is interesting that PP had a higher association for word *comprehension* than for word *attack,* and implies that for this sample of CI children, phonological processing is related to more than decoding, rather it is also facilitates understanding of words. Perhaps better PP skills acts to free up resources by facilitating decoding.

Comprehending Passages

Both groups comprehended passages at the early fifth-grade level. For the NH children, this was slightly higher than the average age of the group (9 years; 6 months) would predict (as evidenced by the standard score as well). For the CI children, who's ages were on average 11 years; 8 months, the performance was at the lower end of the normal range. This level of reading comprehension was, however, above the levels typically seen by children with profound hearing loss (e.g. Traxler, 2000) and replicates earlier studies of reading achievement seen in CI children (Geers, 2003, Spencer, et al., 1997). The difference with this study, compared to previous studies, is that I can begin to explain what contributes to this level of reading achievement—phonological processing skills.

Phonological Processing skills accounted for 43% of the variance in *Passage Comprehension* skills for both the CI and NH children. PP skills appear to account for less variance in passage comprehension than it did for either word attack or word comprehension. This is not surprising; passage comprehension is a more complex skill than word attack or word comprehension because there are more skills, such as language proficiency, world knowledge, ability to use inference, that play a role in passage comprehension. With this in mind, recall that I found that for the CI group each of the component PP skills were moderately correlated with passage comprehension, and the correlations were higher for the CI children than they were for the NH children.

Similar reading levels and similar PP levels?

Both groups of children in this study were decoding words at the early 9^{th} grade level as indicated by figure 9 (p. 84) Both groups were also reading words and comprehending passages at the early fifth-grade level (figure 9). Additionally, the relationship between PP skills and reading was strong for each group. At first blush, it appears that the groups differed, however, in their overall PP skills, such that the NH children had better PP skills. To review, for PA tasks, the CI children had lower mean scores for *Elision* testing, yet there was not a significant difference between groups. Both groups performed similarly on the *Rhyme task*. For the *Blending Words* task, the CI children had significantly lower mean scores. For PM, tasks, the CI children had lower mean scores for *Digit Repetition,* and *Nonword Repetition*, but for the *Digit Span* task, which controlled for input modality, scores were similar. For the Rapid Naming tasks, there were no significant differences on mean performance on either task. One way of interpreting these results is to say that the CI children achieved the same reading levels as the NH children, but with lower levels of PP skills. This outcome suggests that there are subtle ways that the CI children may go about the reading process differently from the NH children.

There are several explanations for why CI children may use alternate ways of reading. Recall the discussion (p. 25) of the Jackson and Dollinger (2002) study on "resilient readers" who had average to above average text comprehension in spite of having poor decoding skills. While the authors were not able to specify what accounted for these readers' ability to compensate, Jackson and Dollinger speculated that the resilient readers might have had superior abilities or tendencies to use contextual cues for comprehension. In the current study, the CI children were resilient readers who had good decoding skills but somewhat weaker PP skills, or it could be that decoding skills are more related to reading than are PP skills. Leach, Scarborough and Rescorla (2003) described readers with similar characteristics (a subtype of reading disorder marked by problems with PP skills), yet they had fairly intact general reading comprehension skills. Bruck (1990) proposed that individuals with this subtype of reading difficulty make educated guesses based on context, which enables them to comprehend the material at hand. This proposal may also serve as an explanation of what the CI children are doing during the reading process. The CI children in the present study are older than their reading-matched cohorts with NH and they, therefore have been in school longer. It could be that the CI children's experience in the classroom and with educational materials allows them to use context during the reading process. Alternatively, perhaps children with hearing loss just naturally learn to rely on context as an adaptive, compensatory strategy for much of their learning, and the application of this skill comes naturally in the context of reading.

An alternative explanation regarding the relationship between PP skills and reading for the CI children is that the skills are *not* lower for the CI children if we measure them correctly. It is possible that when the items are *accessible* to the CI children, their PP skills are commensurate with their hearing peers.

Clinical Implications

It was previously thought that one could not measure PP skills in deaf children. The results of this investigation reveal that it is *reasonable, possible* and *important* to administer a series of tasks to measure the PA and PP skill of children who use CIs. It is *reasonable* to assess early speech production and speech perception skills in order to gain a general indication of how intact the child's skills are, because these listening and speaking skills can predict and are related to future reading outcomes.

It is *possible* to ascertain a measure of PP skills in profoundly deaf children who wear CIs. In this study, all of the children were able to complete all of the tasks administered. Assessment of rhyming was possible through a picture identification task, and assessment of sound-based tasks was possible even through using standard test materials provided by a commercial test distributor. Twenty-eight of the twenty-nine children were able to identify open-set stimuli words that were spoken and presented in an auditory-only condition. Not only were the children able to perceive the stimuli, they had the articulation skills necessary to produce spoken responses. In this particular set of participants, the average age at implantation was just over three years and six months, the average length of CI experience was 8 years, and the children could produce nearly 88% of sounds correctly on a sentence repetition task. One could predict that with early identification of profound hearing loss, and earlier implantation, that the listening and speaking skills of the CI children will continue to be well-developed in the future.

Additionally a possible phonological processing test battery for children who have several years of CI experience and who are beginning to read should include a rhyme task, an elision task, a visual/auditory digit span task as described above, and a letter naming task. The results of this study indicate that although children with CIs can complete tasks in an auditory/only condition, the auditory/visual testing condition may be a more accurate measure of the actual PP skills, and is not as susceptible to artifact from the degraded sound signal. A challenge with the current version of the blending and non-word repetition-type tasks are that young children, particularly those with CIs, find the tasks quite difficult and therefore they are open to floor effects.

Finally the present study illuminates the *importance* of assessing the PP skills in children with CIs. There is a strong relationship between PP skills and reading skills in children with CIs, just as there is a strong association between PP and reading achievement in hearing children. With assessment, we can potentially identify those CI users who are significantly below their peers with respect to their phonological abilities, and consequently which children need extra intervention to increase their phonological skills. The results of the study indicate that clinicians can use PP assessment information to identify a particular child's areas of strength and weakness regarding phonological skill development. Furthermore, given the relationships between early speech production, listening and later reading, plus the relationships between PP and reading, it would be prudent to integrate phonological awareness and processing goals into the speech-language therapy goals for children with CIs. We can expect that remediation of PP should have a subsequent positive effect on the development of reading skills.

Finally the results of the current study suggest that it is appropriate and vital to incorporate background on the relationship between PP skills and reading into the curriculum of training programs for those professionals who are stakeholders in teaching hard-of-hearing and deaf children. In light of the current results, studies by Hanson (1989), Nielsen & Luetke-Stahlman (2002) are right to be critical of instructional methods for deaf and hard-of-hearing that do not incorporate sound-based reading strategies into the curriculum.

Future Studies

I described and detailed the relationship between listening, speaking, phonological processing and reading in this study. I did not, however, directly investigate the effects of using a CI on expressive or receptive language skills, vocabulary development, PP and reading. The literature with NH children would suggest that there is a link between the ability to hear sounds, identify words, and build language and vocabulary knowledge. In early childhood, vocabulary is represented at a holistic level that gradually becomes arranged in terms of phonemic segments in order for the child to make distinctions between words that sound the same (Jusczyk, 1993; Metsala, 1999; Werker & Tees, 1999). For children with CIs, and hearing loss in general, limited audibility makes many phonemes hard to distinguish one from another and these sounds may continue to sound similar for a protracted time period. These "developmental changes in the nature of basic speech representations play a crucial role in the emergence of phoneme awareness and early reading ability" (Garlock et al., 2001, p. 469). We continue to need more research to tease apart the reciprocal nature between PP, decoding words that are known to the learner, learning and decoding new vocabulary, and reading in children who hear a distorted acoustic signal. Such research would help to define what is "necessary" in the acoustic signal and what is "sufficient" for reading.

Additionally, many of the skills that make good language-learners are also the skills that influence reading ability (e.g. having a strong vocabulary, grammar and inferencing skills). Given this relationship, there are a number of issues to continue to explore. For example it would be valuable to understand more thoroughly the contribution of listening, speaking skills and PP skills to vocabulary development. Finally, there were a few children with CIs in the present study who appeared to follow the pattern of the "resilient reader". That is, these children had relatively weak PP skills, but fair to good reading skills. In these children, is it the case that while their PP skills were not strong, the PP skills were strong *enough* to contribute to reading? Alternatively, did these children have other, well-developed compensatory skills that could work with in conjunction with the PP skills?

Listening, Speaking, Phonological Processing and Reading

In this study I showed that *early* speech perception and production skills were relatively strongly correlated with later word and passage comprehension. The regression analysis revealed *early* speech and listening skills accounted for 59% of the variance in later *Word Comprehension* and 62% of the variance for *Passage Comprehension.*

Additionally, both the early and the contemporaneous speech production and speech perception skills of 29 children were modestly correlated with the PP skill of *Elision*, while the early speech production and perceptions scores were modestly correlated with the PP skill of naming. Finally the early speech production and perception scores of the larger group of 72 CI children were highly correlated with later speech production and perception goals. These concurrent findings suggest the following: 1) *early* speech production and perception is related to later reading skills in children with NH and CIs; 2) contemporaneous speech production and perception is related to PP; and 3) contemporaneous speech production and perception skills are strongly related to *early* speech production and perception. This chain of relationships suggests that it is likely that reading skills do not drive PP skills, nor does it suggest that reading skills drive speech production and listening skills. Instead, while it is always difficult to make a causal statement between PP and reading, for the group of CI children in this study it is reasonable to assume that PP skills come out of speech production and sound perception, rather than from learning to read. This is not to imply that there is no reciprocal relationship between reading and PP but that for children who use CIs it is plausible and probable that PP arises out of early speech perception and production skills and that these skills seem to have a crucial relationship to PP.

Conclusions

The early speech perception and production skills of children with profound hearing loss who receive CIs are predictive of future reading achievement skills. Better early speech perception and production skills result in higher reading achievement. Furthermore, the early access to speech sounds helps to build better phonological processing skills, which is one of the likely contributors to eventual reading success. Thus, it is reasonable, possible and important to assess the early speech production perception and subsequent phonological processing in children with profound hearing loss who receive CIs. Early identification and remediation of deficits in phonological processing skills in these children should facilitate eventual word decoding and reading comprehension skills in these children. Future investigation into the nature of the associations between listening, speaking, phonological processing, language and reading is indicated in order to provide additional insights into this complex relationship.

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APPENDIX A

DEMOGRAPHIC INFORMATION FOR PRELIMINARY STUDY

ID	SEX	Age at Implant	Age At Testing	SES	Etiology	CI type	Processing Strategy
1	M	40.3	7.50	4	CNX 26	Nucleus Spectra	SPEAK
2	M	33.4	6.90	4	CNX 26	Nucleus Spectra	SPEAK
3	F	26.4	6.19	5	CMV	Nucleus Sprint	ACE
4	M	66.0	9.55	4	Meningitis	Nucleus Spectra	SPEAK
5	M	45.7	7.66	5	Unknown	Nucleus WSP	FOF1F2
6	F	48.7	8.96	3	Meningitis	Nucleus MSP	MPEAK
7	F	63.5	9.16	4	Unknown	Nucleus MSP	MPEAK
8	M	49.0	8.13	4	Meningitis	Nucleus MSP	MPEAK
9	F	61.1	9.18	3	Meningitis	Nucleus MSP	MPEAK
10	F	15.0	5.27	4	Meningitis	Nucleus 3G	ACE
11	F	43.6	7.67	5	CMV	Nucleus MSP	MPEAK
12	M	19.4	5.61	5	Unknown	Nucleus Sprint	ACE
13	M	12.8	6.10	5	Unknown	Nucleus Sprint	ACE
14	M	61.7	9.54	4	CMV	Nucleus MSP	MPEAK
15	F	15.1	5.35	5	CNX 26	Nucleus Sprint	ACE
16	M	19.5	5.56	5	Unknown	Nucleus Sprint	ACE
17	F	27.0	7.07	2	Unknown	Nucleus Sprint	SPEAK
18	F	56.6	8.83	4	Unknown	Nucleus MSP	F0F1F2
19	M	70.5	9.90	5	Meningitis	Nucleus MSP	F0F1F2
20	M	13.7	5.30	5	CMV	Nucleus Sprint	SPEAK
21	M	60.9	9.09	4	Unknown	Nucleus Sprint	ACE
22	F	65.5	10.05	3	CMV	Nucleus MSP	MPEAK
23	M	33.4	7.07	3	CNX 26	Nucleus MSP	MPEAK
24	F	18.1	5.44	6	Unknown	Nucleus Sprint	ACE
25	M	34.7	7.06	3	Cochlear Mal	Nucleus Sprint	ACE
26	M	16.6	5.33	3	Meningitis	Nucleus Sprint	ACE
27	M	45.0	7.97	5	Meningitis	Nucleus MSP	MPEAK
28	F	73.8	10.08	5	Her NS	Nucleus 3G	ACE
29	F	67.8	9.48	5	Unknown	Nucleus MSP	MPEAK
30	M	64.0	8.61	5	Unknown	Nucleus Spectra	SPEAK

Note: CNX 26 = GJBT mutation (Connexin 26); CMV= Cytomegalovirus; Her NS= nonspecific hereditary component.

ID	*M/F*	*Age at Implant*	*Age At Testing*	*SES*	*Etiology*	*CI type*	*Processing Strategy*
32	M	65.5	9.56	4	CNX 26	Nucleus MSP	MPEAK
33	F	61.6	9.15	5	Unknown	Nucleus MSP	MPEAK
34	F	18.4	5.65	5	Unknown	Nucleus Sprint	ACE
35	F	23.3	6.22	2	Unknown	Nucleus Sprint	ACE
36	F	40.4	7.34	4	Unknown	Nucleus Sprint	ACE
37	F	12.1	5.05	3	Her NS	Nucleus Sprint	ACE
38	F	26.7	6.31	3	Her NS	Nucleus Sprint	SPEAK
39	M	67.0	9.68	4	Meningitis	Nucleus Sprint	ACE
40	M	41.1	7.45	5	Meningitis	Nucleus MSP	MPEAK
41	F	41.2	7.79	5	Unknown	Nucleus Spectra	SPEAK
42	F	39.2	7.33	4	Unknown	Nucleus Sprint	ACE
43	M	65.2	9.30	4	Unknown	Nucleus Spectra	SPEAK
44	M	42.5	7.45	3	Unknown	Nucleus Sprint	ACE
45	M	39.6	7.52	4	CNX 26	Nucleus MSP	MPEAK
46	F	45.5	7.85	5	Unknown	Nucleus MSP	MPEAK
47	F	36.1	7.20	5	Unknown	Nucleus Spectra	SPEAK
48	M	69.7	9.97	3	Ushers Type 1	Nucleus MSP	MPEAK
49	M	41.7	7.77	4	CNX 26	Nucleus Spectra	SPEAK
50	M	15.1	5.24	5	Her NS	Nucleus Sprint	ACE
51	M	29.6	6.59	5	Meningitis	Nucleus MSP	MPEAK
52	M	18.9	5.57	3	Ototoxicity	Nucleus Sprint	ACE
53	F	51.3	8.31	3	Unknown	Nucleus MSP	MPEAK
54	M	32.0	6.60	6	CNX 26	Nucleus Spectra	SPEAK
55	F	63.1	9.26	4	Anoxic episode at birth	Nucleus MSP	MPEAK
56	F	79.5	10.75	4	Unknown	Nucleus MSP	MPEAK
57	M	30.1	6.32	5	Her NS	Nucleus Sprint	ACE
58	F	17.5	5.50	3	Cochlear Mal	Nucleus Sprint	ACE
59	M	38.5	7.22	4	Her NS	Nucleus Sprint	ACE

Note: CNX 26 = GJBT mutation (Connexin 26); CMV= Cytomegalovirus; Her NS= nonspecific hereditary component.

ID	M/F	Age at Implant	Age At Testing	SES	Etiology	CI type	Processing Strategy
60	F	60.2	9.13	3	Meningitis	Nucleus MSP	MPEAK
61	F	18.6	5.70	4	CNX 26	Nucleus Sprint	ACE
65	M	74.7	10.19	5	CNX 26	Nucleus Spectra	SPEAK
66	M	50.1	8.11	4	Unknown	Nucleus 3G	ACE
67	F	53.2	9.23	2	Unknown	Nucleus MSP	MPEAK
68	F	50.0	8.13	5	Unknown	Nucleus Spectra	SPEAK
69	F	88.1	11.62	2	Ototoxicity	Nucleus WSP	FOF1F2
70	F	32.7	7.06	4	Unknown	Nucleus Spectra	SPEAK
71	F	32.6	7.34	3	Unknown	Nucleus MSP	MPEAK
72	F	57.8	9.00	5	Meningitis	Nucleus MSP	MPEAK

Note: CNX 26 = GJBT mutation (Connexin 26); CMV= Cytomegalovirus; Her NS= nonspecific hereditary component.

Table 18. Demographic information for preliminary study

APPENDIX B

DEMOGRAPHIC INFORMATION FOR CI GROUP

ID	*Sex*	*Age at CI*	*Age at Testing*	*Months Experience*	*SES*	*Etiology*	*CI type*	*Processing Strategy*
CI 1	M	2.58	17.83	183.00	5	Meningitis	Nucleus 22 Sprint	MPEAK
CI 2	F	2.32	8.16	70.13	3	Unknown	Nucleus 22 Sprint	ACE
CI 3	F	1.63	9.64	96.10	6	Ushers	Nucleus 3G	ACE
CI 4	M	2.27	9.25	83.77	4	Heredity,NS	Nucleus 22 Sprint	ACE
CI 5	M	2.74	14.06	135.90	6	CNX 26	Nucleus 22 Spectra	SPEAK
CI 6	M	2.88	16.04	158.03	3	CNX 26	Nucleus 22 Esprit	SPEAK
CI 7	M	3.39	16.73	160.07	4	CNX 26	Nucleus 22 Esprit	SPEAK
CI 8	M	1.74	7.89	73.73	3	Unknown	Nucleus 22 Sprint	ACE
CI 9	F	1.59	8.71	85.43	6	Unknown	Nucleus 3G	ACE
CI 10	M	3.57	15.94	148.53	4	CNX 26	Nucleus 22 Spectra	SPEAK
CI 11	F	6.24	13.30	84.70	4	Heredity,NS	Nucleus 22 Sprint	ACE
CI 12	M	3.34	9.74	76.83	4	Heredity,NS	Nucleus 3G	ACE
CI 13	F	10.54	15.43	58.63	4	Unknown	Nucleus 3G	ACE
CI 14	F	3.36	9.44	72.93	4	Unknown	Nucleus 22 Sprint	ACE
CI 15	M	4.27	8.23	47.50	4	Unknown	Nucleus 3G	ACE
CI 16	F	3.53	15.92	148.70	5	Unknown	Nucleus 22 Esprit	SPEAK
CI 17	M	1.64	8.53	82.70	3	Ototoxic	Nucleus 3G	ACE
CI 18	M	1.48	8.43	83.40	4	Meningitis	Nucleus 22 sprint	ACE

ID	*Sex*	*Age at CI*	*Age at Testing*	*Months Experience*	*SES*	*Etiology*	*CI type*	*Processing Strategy*
CI 20	M	5.68	12.81	85.63	4	Unknown	Nucleus 3G	ACE
CI 21	F	2.27	8.25	71.73	5	CMV	Nucleus 3G	ACE
CI 22	M	2.98	11.99	108.07	3	Coch Mal	Nucleus 22 Sprint	ACE
CI 23	F	1.61	8.06	77.43	5	Unknown	Nucleus 3G	ACE
CI 24	M	2.60	10.59	95.93	5	Heredity,NS	Nucleus 22 Sprint	ACE
CI 25	M	1.69	7.19	66.07	5	Unknown	Nucleus 22 Sprint	ACE
CI 26	F	10.99	15.13	49.77	4	Unknown	Nucleus 3G	ACE
CI 27	M	3.82	16.89	156.87	5	Meningitis	Nucleus 22 Esprit	SPEAK
CI 28	M	3.53	11.85	99.87	3	Coch Mal	Nucleus 3G	ACE
CI 29	F	2.34	11.40	108.73	3	Heredity,NS	Nucleus 3G	ACE
Average		**3.55**	11.88	99.97	4.24			
SD		**2.39**	3.50	36.80	0.95			

Note: CNX 26 = GJBT mutation (Connexin 26); CMV= Cytomegalovirus; Heredity NS= nonspecific hereditary component.

Table 19. Demographic Information for CI group

APPENDIX C

Name	*Sex*	*Age/Test*	SES
NH 1	M	6.51	6
NH 2	F	10.14	5
NH 3	M	9.63	5
NH 4	M	10.82	6
NH 5	M	7.31	5
NH 6	M	6.73	5
NH 7	F	11.35	5
NH 8	F	7.62	5
NH 9	F	10.96	6
NH 10	M	6.44	6
NH 11	M	8.65	4
NH 12	M	7.46	4
NH 13	F	12.18	3
NH 14	F	17.96	3
NH 15	M	6.65	3
NH 16	M	10.14	3
NH 17	M	9.29	4
NH 18	F	13.29	3
NH 19	F	7.51	3
NH 20	M	6.20	4
NH 21	M	7.71	4
NH 22	M	8.48	4
NH 23	M	10.61	3
NH 24	M	13.94	6
NH 25	F	11.58	5
NH 26	M	10.53	5
NH 27	F	8.31	4
NH 28	F	11.49	5
NH 29	F	7.44	4
Ave		9.55	4.41
SD		2.70	1.05

Table 20. Demographic information for NH group.

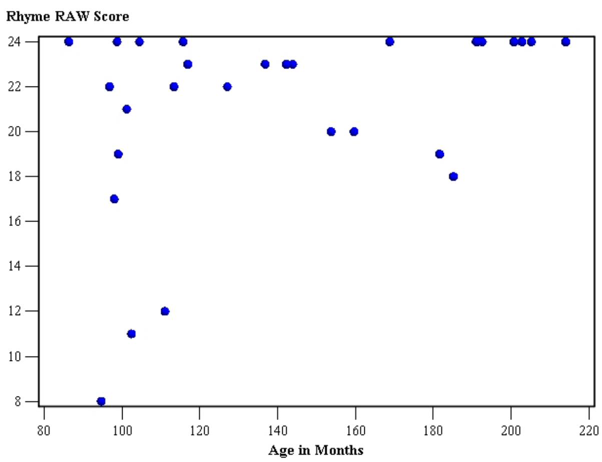
APPENDIX D

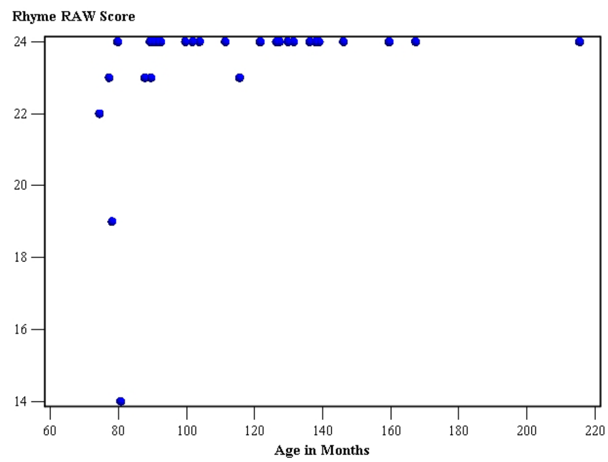
CUE	*TARGET*	*DISTRACTER*	*DISTRACTER*
SOCK	CLOCK	DOLL	HAT
TREE	KNEE	PIE	BIRD
HAND	SAND	SALT	GLOVE
LEG	PEG	NAIL	ARM
SHOE	BLUE	GOLD	FEET
LIGHT	KITE	DUCK	SUN
DRAW	FLOOR	BATH	PEN
WALL	BALL	TIE	WIG
TAP	MAP	RING	TEN
BAG	FLAG	KISS	BEE
FAN	MAN	COAT	FOX
FRUIT	BOOT	DOOR	FROG
SOAP	ROPE	COT	SIX
WHALE	SNAIL	CUP	WIN
KEY	SEA	FARM	KING
NURSE	PURSE	ILL	NIGHT
PINK	SINK	PINK	PULL
FACE	ACE	NOSE	FORK
CAN	PAN	PIPN	BED
FOUR	DOOR	EIGHT	FAT
DRUM	THUMB	TOY	DRIP
HAIR	PEAR	BOW	HILL
BOWL	GOAL	KNIFE	BUS

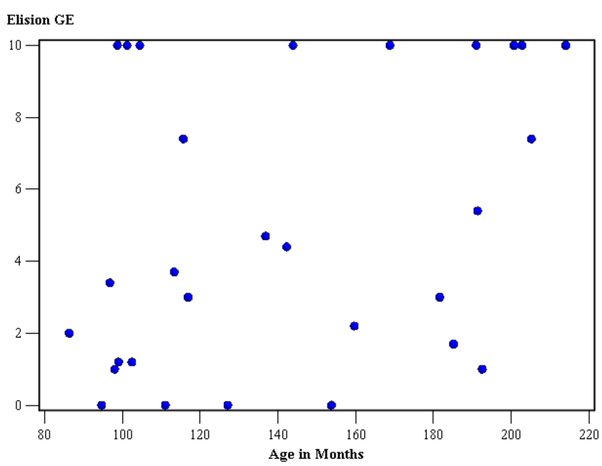
Table 21. List of stimuli for rhyme task.

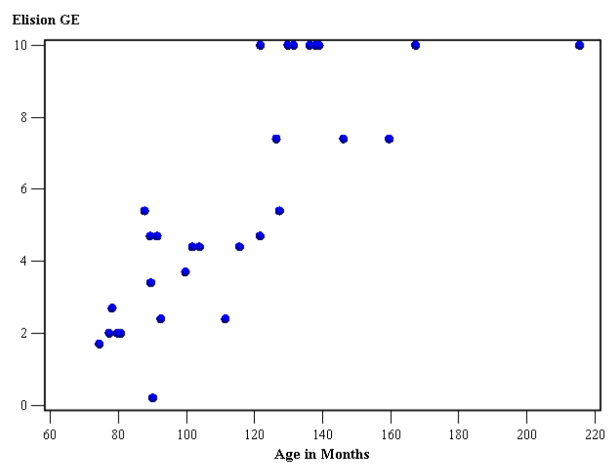
APPENDIX E

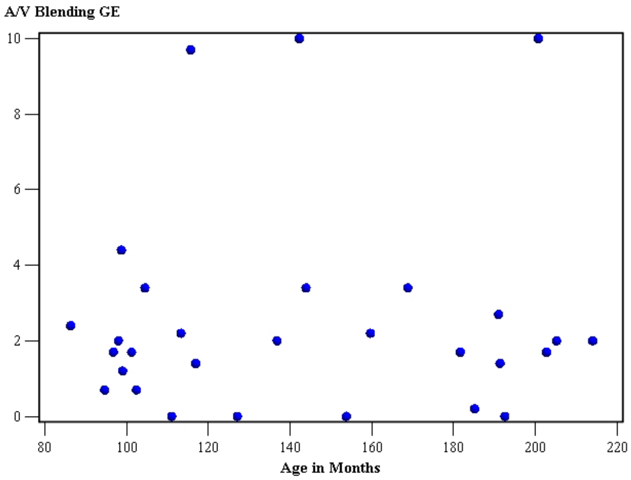
(left panel is CI Group and right panel is NH Group)







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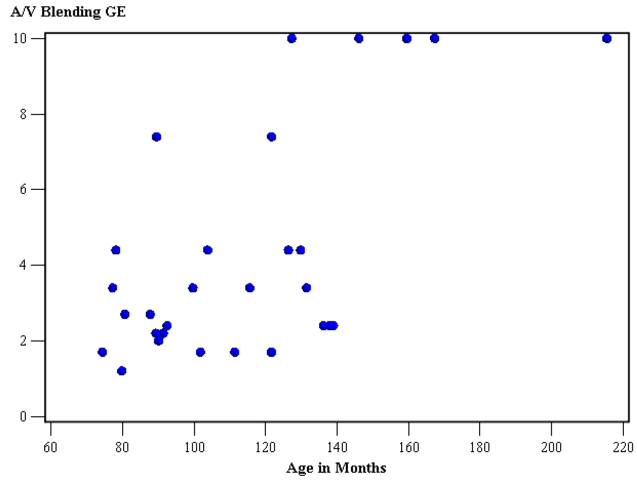
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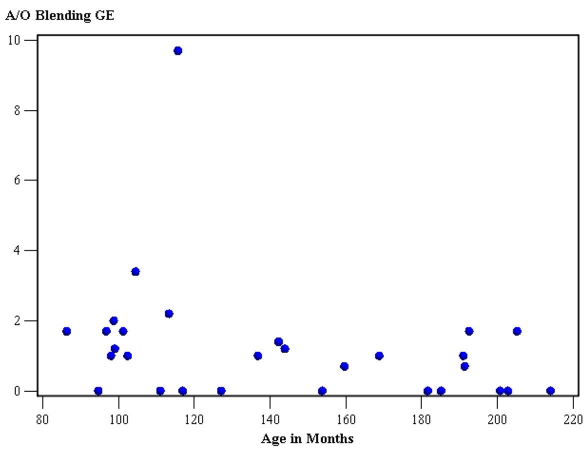
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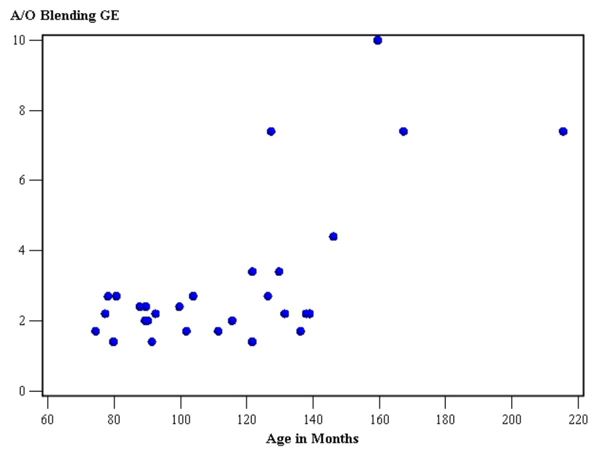
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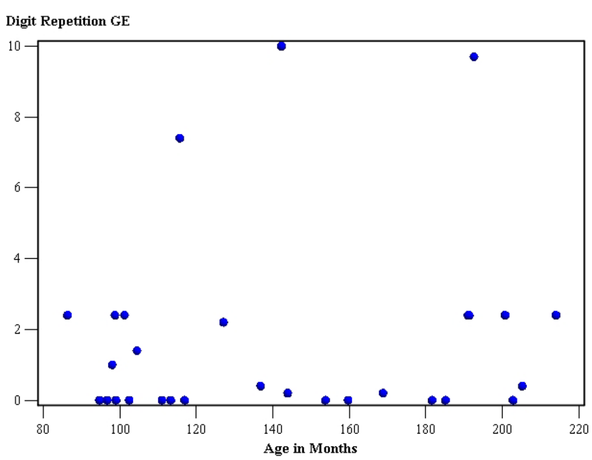
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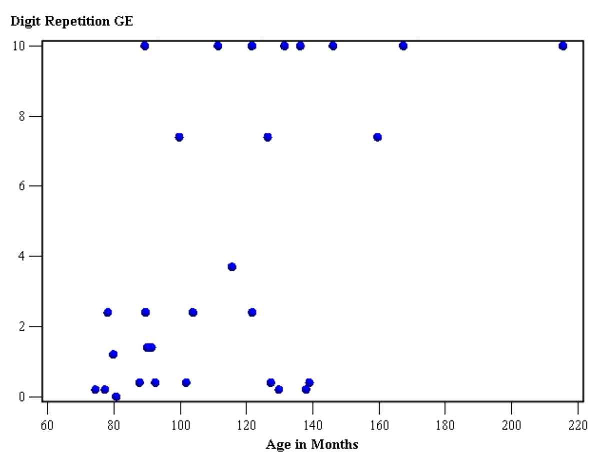
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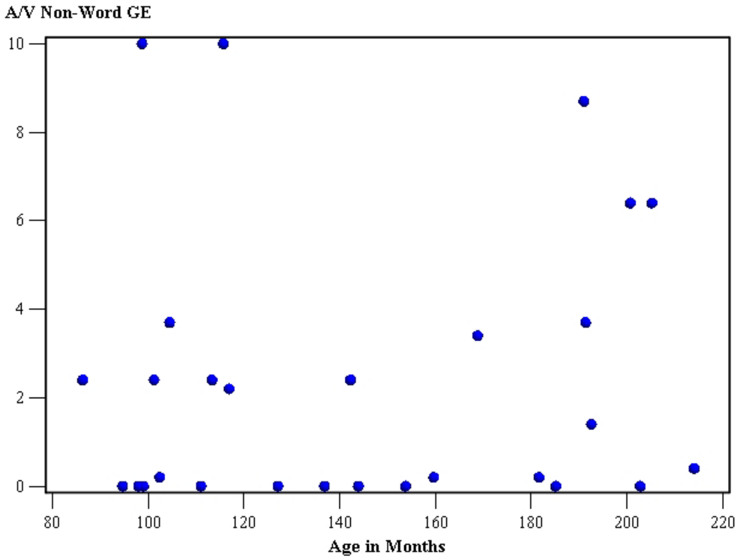
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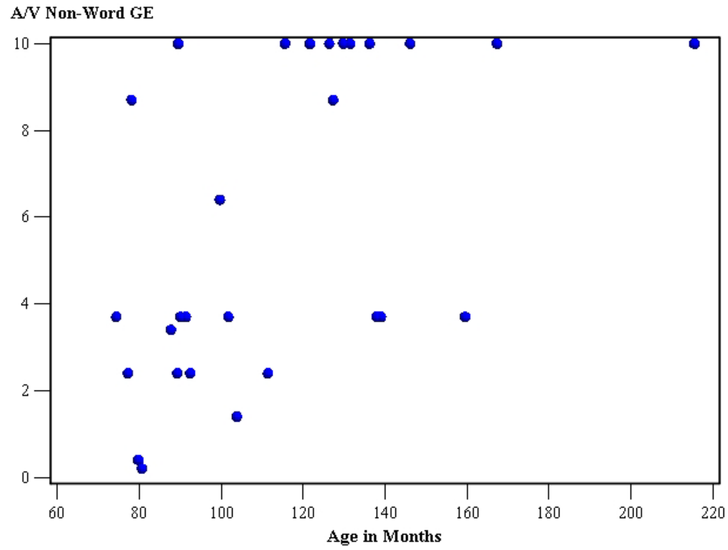
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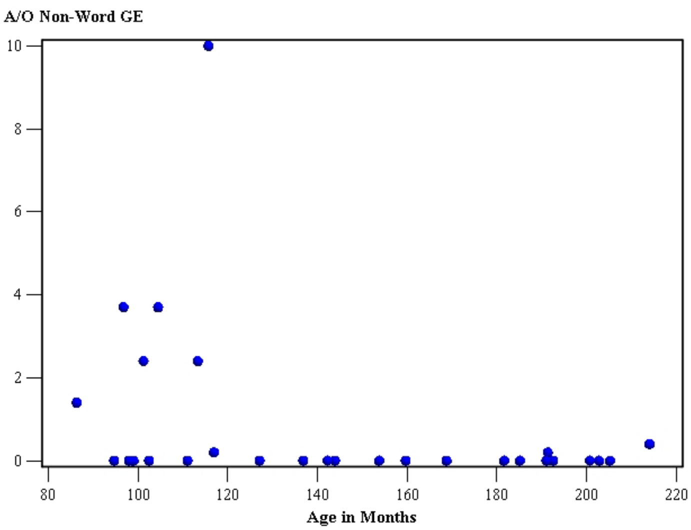
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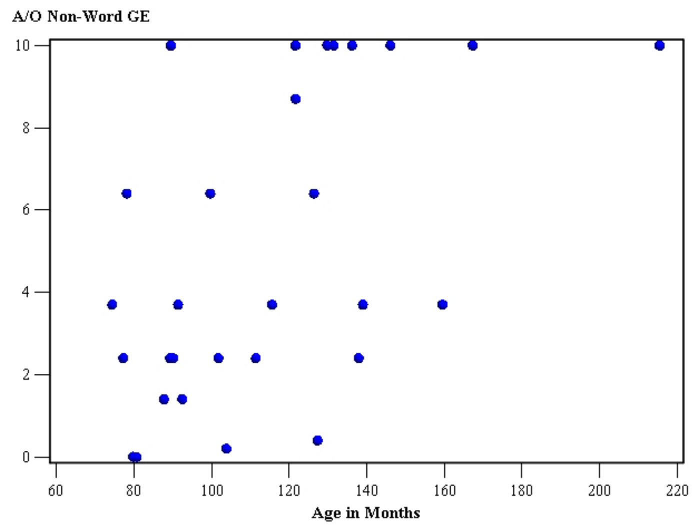
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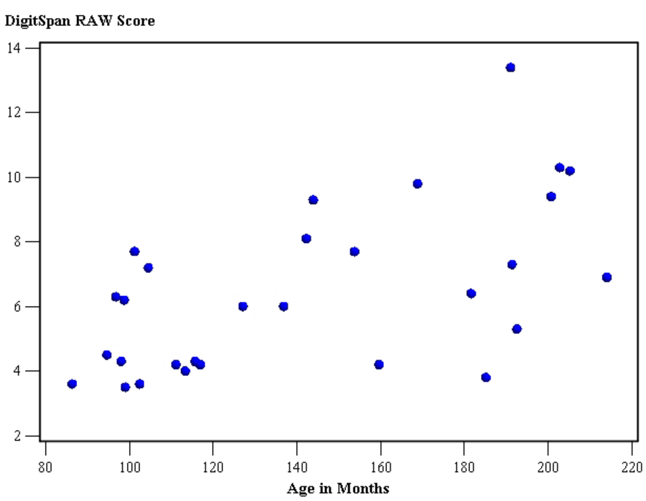
Age in Months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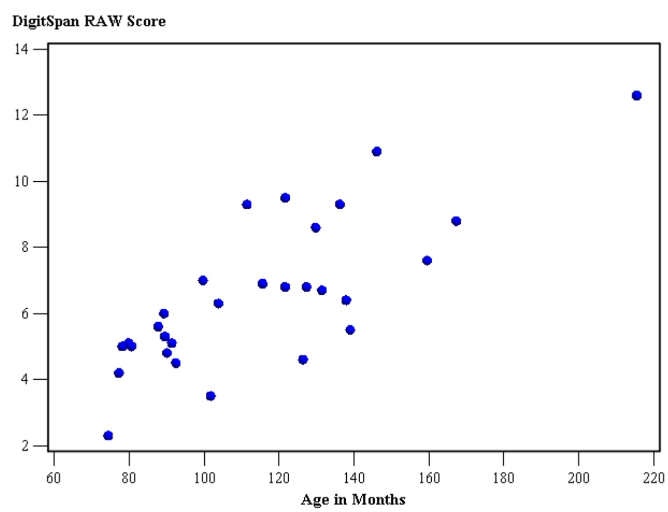
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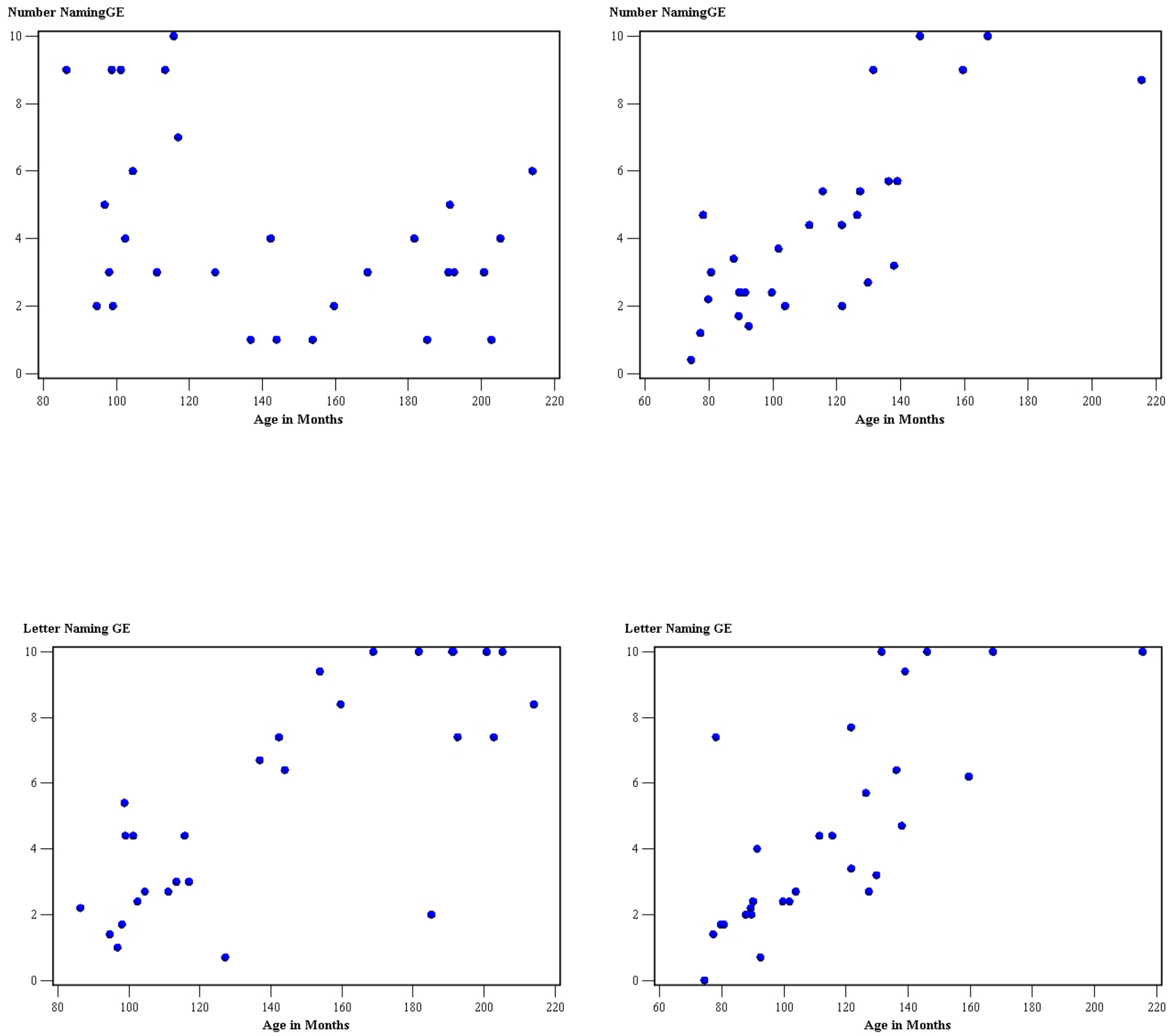

Figure 14. Distribution plots for all PP tasks.