An Investigation of the Reading, Speech, Language and Phonological Processing Skills of Children Using a Cochlear Implant

Kylie von Muenster

A thesis submitted in partial fulfilment

of the requirements for the degree of

Doctor of Philosophy (Speech Pathology)

Discipline of Speech Pathology

Faculty of Health Sciences

The University of Sydney

August 2008

Abstract

Traditionally, children with a significant prelingual hearing loss have attained reading outcomes no higher than fourth grade (Gallaudet Research Institute, 2002; Holt, Traxler & Allen, 1997). With the advent of multi-channel cochlear implantation, children with a significant hearing loss gained the potential to access spoken language and to engage in phonological processing via audition. In children with normal hearing, better reading outcomes have been associated with better phonological processing ability (e.g., Catts & Kamhi, 2005; Griffiths & Snowling, 2001; Muter, Hulme, Snowling, & Stevenson, 2004; Rvachew & Grawburg, 2006; Stackhouse & Wells, 1997; Wagner, Torgesen, Laughon, Simmons, & Rashotte, 1993). While there is some evidence that cochlear implantation is associated with improvements in speech, language and reading outcomes (e.g., Geers, 2003; Geers, Nicholas, & Sedey, 2003b; Spencer, Barker, & Tomblin, 2003; Thoutenhoofd, 2006; Tomblin, Spencer, Flock, Tyler, & Gantz, 1999), less is known about the phonological processing abilities of these children. Furthermore, although the outcome research has generally been positive, there has been great variability in performance both within a cohort of children and across studies. Heterogeneous participant profiles, particularly the varying modes of communication used by participants, have made it difficult to draw meaningful conclusions about factors associated with good reading outcomes for children using a cochlear implant.

There is a need to determine the reading, speech, language and phonological processing abilities of a homogenous cohort of children using a cochlear implant. Further there is a need to explore whether factors associated with reading outcomes in children with normal hearing such as phonological processing, are also related to reading outcomes in children using a cochlear implant. This thesis documents the reading outcomes, and skills related to reading outcomes in a relatively homogenous group of children who use a cochlear implant and oral communication. The relationships between the children's performance on tasks of word reading, reading comprehension, speech perception, speech production, language and phonological processing are explored to provide a big picture view of which skills might be related to good reading outcomes.

A group of 47 children using a cochlear implant and oral communication, and who had attended auditory-verbal therapy (AVT), served as the participants. All participants undertook a battery of 10 different assessments covering 22 different tasks in the areas of reading (word reading and reading comprehension), speech (production and perception), language and phonological processing abilities.

Despite the participants having similar communication mode and education profiles, variation in performance was evident across tasks and among participants. For example, participants reading scores ranged from 2 standard deviations below the normal range to 2 standard deviations above the normal range. A series of group trends were evident. Firstly, while the participants had word reading skills commensurate with children with normal hearing, their reading comprehension skills were poor. The participants' speech perception skills were poor compared with children who have normal hearing. The participants' production of polysyllabic words was poorer than their production of mono- disyllabic words. In comparison to typically developing children with normal hearing, the participants' language skills were poor. In the area of phonological processing, phonological retrieval was good, phonological working memory was poor, while phonological awareness was good for only half the

participants. Targeted demographic variables were not significantly related to reading outcomes, with the exception of number of children in a family (a nonlinear relationship). Investigation of the relationships between the skills tested revealed that language and word reading were most strongly related to reading comprehension, while phonological awareness and language were most strongly related to word reading. It is proposed that good reading outcomes are linked to better language and phonological processing abilities, and that the development of well-specified phonological representations might underlie these relationships.

Ethics Statement and Declaration

I, Kylie von Muenster certify that the work contained within this thesis is my own and has not been submitted to any other university or institution as a part or whole requirement for any higher degree.

The research proposal was approved by The University of Sydney Human Ethics Committee (Reference number: 00/12/02). The research was conducted in accordance with the National Health and Medical Research Committee's guidelines on human experimentation. Participant confidentiality was ensured.

[redacted] 12/2/09

Candidate's signature Date

I certify that Kylie von Muenster's thesis is ready for submission.

[redacted]

Presentations Arising from this Thesis

- Rattigan[1], K., Reed, V.A., & Lee, K. (2002, February). *An investigation of the phonological processing and word reading efficiency skills of cochlear implant users*. Presented at the 6th European Conference on Paediatric Cochlear Implantation – Las Palmas, Canary Islands, Spain.
- Rattigan, K., Reed, V.A., & Lee, K. (2002, May). *An investigation of the phonological awareness and reading accuracy skills of children using a cochlear implant*. Presented at the International Conference of the International Clinical Phonetics and Linguistics Association – Hong Kong.
- Rattigan, K., Reed, V.A., & Lee, K. (2002, July). *An investigation of the phonological processing and literacy skills of children using a cochlear implant in an oral educational setting*. Presented at the A.G. Bell Association for the Deaf and Hard of Hearing 2002 Convention, St. Louis, U.S.A.
- von Muenster, K., Baker, E. & Lee, K. (2007, November). *An investigation of the word reading and phonological processing skills of children using a cochlear implant*. Presented at the Biennial Faculty of Health Sciences Postgraduate Research Student Conference - Sydney, Australia.

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[1] The research students surname changed from Rattigan to von Muenster.

A Note on Style

- The term significant hearing loss is used to refer to a child with a hearing loss in the severe – profound range.
- As is customary in the literature on children with cochlear implant, the participants' ages are documented as years;months (e.g., 4;2 for "four years and two months").
- In studies where ages are presented as a proportion of a year, a decimal point is used between the number of years and proportion of the year (e.g., 12.75 for 12 years and 9 months).
- The following abbreviations are used throughout the thesis:

  -AVT = auditory-verbal therapy

  -OC = oral communication

  -TC = total communication

  -CI = cochlear implant

  -SCIC = The Sydney Cochlear Implant Centre

  -MDSWs = mono-disyllabic words

  -PSWs = polysyllabic words

Acknowledgements

I would like to express my gratitude for the efforts of some amazing people who supported me in this research. This thesis would not have been completed without your support. I would especially like to thank:

- My supervisors, Dr Elise Baker and Dr Kerrie Lee. I feel so fortunate to have had two of the most caring, dedicated and intelligent supervisors. Elise, you were wonderful in providing both the academic and emotional support that I needed while writing this thesis. You rode the ups and downs with me, always made time for me and so importantly, you kept me focused on the 'big picture' and the path to completion. Kerrie, during this writing of this thesis and even in retirement, you so generously gave of your time and wisdom. I am so grateful and indebted to you both. Thank you also to Professor Vickie Reed for getting me started and supervising me in the early stages of this thesis.
- The staff and students of the Faculty of Health Sciences. Thank you for the encouragement to keep at it. I would especially like to thank Dr Rob Heard, for his assistance with the statistics.
- The children and families who participated in the research. You were the inspiration for this research. Thank you for giving your precious weekends to do the assessments.
- Mr Chris Rehn and the staff from the Sydney Cochlear Implant Centre. I am grateful for the support and encouragement you provided in the early stages of this research.

- My parents, Pamela and Peter Rattigan, thank you for your love and support for the duration of the thesis. Dad you always had a piece of advice to give whenever I called – thank you for caring. Mum thank you for flying across the country to give your help and babysitting services when most needed.
- My husband Stephen, and daughters Milena and Clementine. Thank you for your ongoing love and support, and hanging in there with me. You had to endure a somewhat tired and distracted wife and mummy. Thank you for your patience. Looking forward to many relaxing fun family times ahead.

Preface

As a speech-language pathologist I have had a long-standing interest in reading difficulties in children and have followed the accumulating research evidence about the relationship of oral language and literacy in children. In particular, this research has suggested that phonological processing is important in developing reading ability. Put simply, phonological processing is a generic term that refers to the use of phonological information to process spoken and written language (e.g., Catts, 1989; Catts & Kamhi, 2005; Gillon, 2004; Passenger, Stuart, & Terrell, 2000; Stackhouse & Wells, 1997; Wagner et al., 1993).

When I first began to work with children with a hearing loss more than 10 years ago, I soon learned that this population had poor outcomes in reading. A report by Holt, Traxler and Allen (1997) that children born with a significant hearing loss attain reading outcomes no higher than Grade 4, is typical of reports over several decades documenting poor reading outcomes in children with significant hearing loss. Despite this, there was no research looking at their phonological processing abilities and I began to wonder if the reading difficulties reported for children with a significant hearing loss were related to their limited access to the phonological features of spoken language. Working in a specialist centre, which provided services solely to children using a cochlear implant, I learned that these children could develop spoken language using their listening. With the potential to engage in phonological processing and improve oral language skills, I expected to see improved reading outcomes. Clinically, what I observed was enormous variability in their reading ability. This thesis documents my research into the factors that underlie outcomes in reading for children with a significant hearing loss who use a cochlear implant.

Synopsis

This thesis reports a study on the reading, speech and language and phonological processing abilities of a group of 47 children using a cochlear implant and oral communication. Chapter 1 provides a broad overview of current research documenting outcomes for children using a cochlear implant and the factors affecting these outcomes. The review in chapter 2 then focuses on research into spoken and written word processing, reading and phonological processing in both children with normal hearing and children with a significant hearing loss. This review suggests that research regarding reading development and problems, and particularly the relationship of reading with phonological processing abilities of children with normal hearing, could help to inform our understanding of the reading outcomes of children using a cochlear implant, whom via the implant have gained the potential to engage in phonological processing.

Chapter 3 details the method of the four parts to the study, all of which use the same cohort of 47 children. Each of these parts is reported separately in chapters 4 to 7. Chapter 4 presents and discusses the profiles of the participants' reading outcomes, and assesses the impact of demographic and implant-related variables to reading. Chapter 5 reports on the profile of the participants' outcomes in receptive and expressive language, speech production and speech perception. Chapter 6 presents and discusses the participants' phonological processing (phonological working memory, phonological awareness and phonological retrieval) abilities. In chapter 7 the relationships between each of the outcome areas is presented. In chapters 4 to 7 directions for future research are posited. The final chapter (chapter 8) concludes with a discussion of the strengths and limitations of the study.

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Chapter 1. Outcomes Reported for Children Using a Cochlear Implant

"The bionic ear has opened up a whole new world to deaf children. Helped by the plasticity of their brains in adjusting to new signals, they can now stand equal to their hearing peers in their ability to communicate through the use of spoken language"

(Professor Graham Clark, 2007)

1.1. Introduction

A child born with a profound hearing loss cannot adequately hear speech sounds and will not fully develop speech or oral language unless they are fitted with a prosthetic hearing device and provided with habilitation to teach them to attend and interpret the auditory signal. Even when this is done, there is an extensive body of research that has consistently found that children born with a profound hearing loss have significant speech and language delay relative to their normal hearing peers (e.g., Davis & Hardick, 1981; McCaffrey, Davis, MacNeilage, & von Hapsburg, 1999; Tobey, Geers, & Brenner, 1994). The delay in oral language is accompanied by delays in written language, in particular reading (Harris & Beech, 1998; King & Quigley, 1985; LaSasso & Mobley, 1997; McAnnally, Rose, & Quigley, 1994; Paul, 1999). Historically, the children involved in this research used hearing aids, which amplify the speech signal to make it audible. The amplified signal from the hearing aid is then processed by the damaged cochlea and the resulting quality and quantity of sound available to the child for speech perception is limited by the capacity of the damaged cochlea to respond to the frequency and intensity characteristics in the amplified signal. This inherent limitation in hearing aid technology resulted in research to develop an alternative technology that does not use the cochlea to process the auditory signal. Clark (1997) claims that the development of the multi-channel cochlear implant, has provided children with severe to profound hearing loss with improved access to spoken language because the implant bypasses the cochlea and directly stimulates the auditory nerve. Almost 20 years after the first child received a multi-channel cochlear implant, there is emerging evidence that the speech and language outcomes of children born with a significant hearing loss are improving, at least for those fitted with an implant (Blamey, Sarant, Paatsch, Barry, Bow, Wales, Wright, Psarros, Rattigan, & Tooher, 2001; Geers et al., 2003b). This chapter reviews research on the outcomes in speech, language and reading for children using a cochlear implant, and the factors that have been associated with these outcomes. The chapter provides an important foundation for chapter 2, which explores the literature on phonological processing as it relates to reading.

1.2. Speech, Language and Reading Outcomes of Children Using a Cochlear Implant

Studies reporting outcomes for children with a cochlear implant typically compare their performance to children wearing hearings aids (Blamey et al., 2001; Tomblin et al., 1999) and/or children with normal hearing (Dawson, Blamey, Dettman, Barker, & Clark, 1995; Fagan, Pisoni, Horn, & Dillon, 2007). Studies that compare outcomes for devices are usually designed to answer the question of which is the more appropriate for this population, while studies comparing performance of children with hearing loss to their normal hearing peers are focused on the developmental progress of children born with a hearing loss compared to typically developing children. This section reviews both types of studies in the areas of speech (perception and production), language (receptive and expressive) and reading outcomes.

1.2.1. Speech Perception Outcomes

The ability to detect, discriminate and recognize speech sounds is fundamental to the development of oral language. These speech perception skills are typically measured in children with hearing loss using word recognition tasks in which the child is presented with a word or sentence and asked to repeat back the word or sentence, or identify the word from a set of written or pictured response alternatives. Speech perception skills have been shown to improve following cochlear implantation (e.g., Blamey, Dawson, Dettman, Rowland, Brown, Busby, Dowell, Rickards, & Clark, 1992; Dawson, Blamey, Rowland, Dettman, Clark, Busby, Brown, Dowell, & Rickards, 1992; Kirk, Miyamoto, Ying, Perdew, & Zuganelis, 2002b; Pulsifer, Salorio, & Niparko, 2003). The studies report an average percent-correct score using audition alone of 40 - 50% for open-set word recognition (Geers, Brenner, & Davidson, 2003a; Paatsch, Blamey, Sarant, Martin, & Bow, 2004) and approximately 60% for open-set sentence tasks (Geers et al., 2003a; Paatsch et al., 2004). These results indicate that children using a cochlear implant are able to pick up many speech cues using audition alone, although they still miss a significant portion of the signal.

While the detection of speech is a prerequisite for spoken language development, it is not sufficient to indicate if essential cues for discrimination and recognition are available. Open-set speech perception tests attempt to assess these skills. However, the validity of assessing a child's skill at perceiving spoken information using open-set tasks has been questioned. Blamey et al. (2001) found a strong relationship between speech perception scores, language skills, and speech production skills in 47 children using a cochlear implant. They suggested some of the variability in speech perception scores is accounted for by the child's language and speech production skills and concluded that "most children will score above 90% on the open-set BKB sentence test auditory-visually when their language becomes equivalent to that of a 7-year-old child with normal hearing" (p.283).

In addition to this issue of poor validity, the reliability of speech perception tests using short word or sentence lists has also been questioned. Thornton and Raffin (1978) reported on the need to use longer list lengths (up to 100 items) to attain adequate test-retest reliability, while other studies (Sarant, Blamey, Dowell, Clark, & Gibson, 2001) have reported poor inter-tester reliability in scoring open-set speech tests with young children using a cochlear implant.

Despite these issues, speech perception tests have been used extensively clinically and form part of the clinical protocols for audiologists working with children using a cochlear implant and are typically reported in outcomes research (e.g., Blamey et al., 2001; Dowell, Dettman, Blamey, Barker, & Clark, 2002; Geers et al., 2003a; Psarros, Plant, Lee, Decker, Whitford, & Cowan, 2002).

1.2.2. Speech Production Outcomes

The speech production outcomes for children using a cochlear implant has typically been measured using percentage correct speech sounds (Blamey et al., 2001; McDonald Connor, Hieber, Arts, & Zwolan, 2000; Tobey, Geers, Brenner, Altuna, & Gabbert, 2003; Tye-Murray, Spencer, & Woodworth, 1995). Connor et al. (2000a) followed the changes in speech production of children using a cochlear implant for up to 7 years post-implant. They measured percent consonant-correct scores for the children, who included those enrolled in educational programs that used either oral communication (OC) or total communication (TC). The speech samples were elicited from the children using a range of single word picture tests (e.g. Goldman-Fristoe Test of Articulation), however any words produced by the participants during the administration of the test were also analyzed. At 6 months to 1 year post-implantation the mean percentage consonant-correct score for the whole group was 26.1%, and for the children who used OC it was 32%. At 6 to 7 years post-implant the speech production scores rose to a mean percent consonant correct of 68.9% for the whole group and 67.8% for the OC group. These results are similar to a later study by Blamey and colleagues (2001) who found that cochlear implant users, who were all enrolled in an OC program, produced on average 68.7% of singleton consonants[2], 81.3% of monothongs, and 74.6% of dipthongs correct in conversational speech. However, these children scored a mean of only 39.4% words correct in conversational speech. The seemingly low word correct score may be related to the criteria used in their study. The words spoken were transcribed and scored using a narrow phonetic transcription and it is possible that some features, such as nasality, were scored as phonetic errors without affecting intelligibility, as on average only 5.8% of words in the samples were unintelligible.

Connor et al. (2000) found a correlation between speech production scores and age, while Blamey et al. (2001) found these variables were not correlated. This difference may reflect differences in the ages at which the speech production data were collected in the two studies. In the Connor et al study the children were implanted from 2 years of age and the increasing percentage correct scores with age post-implantation may reflect the developmental changes that typically occur in the first 5 years of speech

[2] Consonant clusters were excluded from the analysis.

acquisition. The mean age of the participants in the Blamey et al study was 7;7 years and therefore developmental speech changes were less likely to influence the scores.

Tobey et al. (2003) investigated the speech production outcomes of children using a cochlear implant as part of a larger research project entitled '*Cochlear Implants and Education of the Deaf Child*' conducted by Anne E. Geers and colleagues. Tobey et al used a sentence task in which participants were "shown a written version of the sentence and prompted with a verbal or sign elicitation to repeat the stimulus" (p.38S). The sentences produced were used to measure participants' speech intelligibility (rated on monosyllabic key words only), percentage of correct consonant and vowels produced, duration of sentences, and to conduct an acoustic analysis. In addition a speech usage questionnaire was administered and a conversational analysis conducted to assess communication breakdown. Tobey et al reported the following group mean scores: key word intelligibility was 63.5%; percentage correct for consonants was 68%, and for vowels was 61.6%. The variable most strongly correlated with key word intelligibility scores was percentage consonants correct ($r = .87$). The mean percentage consonant correct score of 68% in the Tobey et al study is similar to the results reported by Blamey et al for conversational speech of 68.7%. However the mean percentage correct score for vowels of participants in the Tobey et al study was lower than the mean percentage correct score for monothongs reported by Blamey et al. Tobey et al found that communication mode significantly contributed to the variance in speech production scores. The discrepancy in the results for vowels may be due to differences in the communication modes used by the participants in the two studies.

Taken together, the results from the speech production outcome research indicate that children using a cochlear implant make errors on both consonants and vowels in sentence tasks and conversational speech, and show that children using a cochlear implant do not to achieve age-appropriate speech production commensurate with their hearing peers. Dodd et al. (2003) reported norming data for 684 typically developing children with normal hearing from 3 years to 6;11 years old. They found that the average percentage vowel and consonant correct scores for typical developing children of between 4;0 and 5;5 years were 98.98% and 90.37% respectively. However only 3 of the 50 stimulus words from the picture naming task used in the Dodd et al study contained polysyllabic words.

One aspect of speech production that has not been considered in the literature of children with a hearing loss either with or without a cochlear implant is word length or the number of syllables in a word. In a search of the literature dedicated to the study of children's production of polysyllables (words of three or more syllables), 16 published studies were identified. Of these studies (Gilbert & Johnson, 1978; Ingram, Christensen, Veach, & Webster, 1980; James, 2001a, 2001b; James, van Doorn, & McLeod, 2001; James, van Doorn, & McLeod, 2002; James, van Doorn, & McLeod, 2008; Kehoe, 1997, 1998, 2000; Kehoe & Stoel-Gammon, 1997a, 1997b; Klein, 1981, 1984; Klein & Spector, 1985; Young, 1991), all had normal hearing and either typical or impaired speech acquisition. None of the participants had a significant hearing loss. A recent published study (Buhler, DeThomasis, Chute, & DeCora, 2007) regarding phonological process use in 5 children using a cochlear implant, used the Goldman Fristoe Test of Articulation 2 (Goldman & Fristoe, 1986) to elicit speech samples. While the researchers analysed words for syllable deletion, of the 53 stimulus words elicited only 3 were polysyllabic. Therefore participants' production of polysyllabic words (PSWs) could not be adequately analysed. Similarly, in a study of the effects of articulation training by Paatsch, Blamey and Sarant (2001) of 12 children, 6 of whom used a cochlear implant, only 3 of 108 stimulus words were polysyllabic. The authors did not comment on the participants' accuracy with regard to PSW production.

Polysyllables are more difficult to articulate than monosyllables or disyllables. James (2006, p.15) noted that, "the compression of constituents within polysyllabic words makes production harder as more rapid articulation is required". Further PSWs have elements such as different levels of stress and weak syllables that are harder to perceive (James, 2006). James (2006) was interested in issues surrounding production of words of differing number of syllables. She conducted a comprehensive study that investigated speech production development in typically developing children with normal hearing from ages 3 to 7;11 years to establish whether there were any effects of syllable length and age on production of words. She looked at monosyllabic, disyllabic and polysyllabic word production in terms of percentage vowels and consonants correct and in terms of the error processes exhibited. James found that for typically developing children, percentage consonants and vowels correct scores increase and error processes decrease from ages of 3 to 7 years. In addition to age effects, James found syllable effects and noted that, "a hierarchical acquisition of words was implied whereby monosyllabic words were acquired before disyllabic words which, in turn, were acquired before polysyllabic words" (p.245). James also noted that for children with normal hearing, accuracy of PSW production has been associated with literacy outcomes. This had previously been reported by Larrivee and Catts (1999), who found that the production of polysyllabic words was related to reading performance in children with normal hearing. This literature does not suggest that production of polysyllables is causally related to literacy success but rather that it is one of many possible factors that covaries with reading in children with normal hearing. The association of PSW production and reading outcomes has not been investigated in children using a cochlear implant.

1.2.3. LANGUAGE OUTCOMES

Several studies have reported that the language skills of children using a cochlear implant are better than children with a similar hearing loss who do not use a cochlear implant (Spencer, Tye-Murray, & Tomblin, 1998; Tomblin et al., 1999). However, studies which have compared the language skills of children using a cochlear implant to their peers with normal hearing have found that the children using a cochlear implant have delayed language (Blamey et al., 2001; Geers et al., 2003b; Spencer et al., 2003), although the rate of their language acquisition increases post-implantation compared to pre-implantation (Dawson et al., 1995; Svirsky, Robbins, Kirk, Pisoni, & Miyamoto, 2000). Studies that have compared the rate of language acquisition post-implantation with the rate expected for typically developing children have produced variable results. Some studies have found that children using a cochlear implant have a slower rate of language acquisition than their normal hearing peers (Blamey et al., 2001; Dawson et al., 1995), while other studies have found that children using a cochlear implant have an equivalent rate of language development to children with normal hearing (Miyamoto, Svirsky, & Robbins, 1997; Svirsky et al., 2000).

Studies of children using a cochlear implant generally do not include communication mode as an inclusion criterion. As a result most studies have a heterogeneous group, typically including participants who are exclusively oral, as well as those who use cued speech and total communication, both of which have a visual component (Dawson et al., 1995; Geers et al., 2003b; Svirsky et al., 2000; Tomblin et al., 1999). Studies examining language skills have often used both signed and spoken presentation of their assessment tasks (Geers et al., 2003b; Spencer et al., 2003; Svirsky et al., 2000; Tomblin et al., 1999) and accepted responses in both these modalities.

Spencer et al. (2003) looked at the language and literacy skills of a group of 16 children using a cochlear implant and simultaneous communication (speech and manually coded English) and allowed sign and speech presentation and responses. The children in their study had an average age at implantation of 47 months. Spencer et al. (2003) used both an expressive and receptive language task from the Clinical Evaluation of Language Fundamentals – 3rd Edition (CELF-3) (Semel, Wiig, & Secord, 1995) as their language measures. The results showed the language of the participants was delayed relative to typically developing children (mean standard score for the expressive language subtest was 5.14, and 7.17 for the receptive language subtest). The receptive subtest required the participants to carry out a given instruction. It is possible that the combined sign and speech presentation of the test items gave the participants the opportunity to use visual memory and processing strategies not available in an oral-only presentation mode and may be one explanation for the comparatively better receptive language.

Geers et al. (2003) investigated the language skills of children using a cochlear implant and a variety of communication modes including OC and TC, and compared their performance to children with normal hearing. The language comprehension tasks were presented using both sign and speech to all children to minimize any advantage of iconicity of signs in assisting the participants who used TC. The receptive language score for the cochlear implant group was typically 3 or more standard deviations below the mean for typically developing children. Only 30% of the cochlear implant group obtained a total receptive language score within the normal range. On expressive language measures such as productive syntax and bound morphemes, less than half the cochlear implant group achieved scores comparable to the normal hearing group.

Blamey et al. (2001) compared the rate of development of speech perception, speech production and language in a group of 47 children using a cochlear implant, and 40 children with a moderate or severe hearing loss using hearing aids, to age-norms for typically developing children. Both groups of children with a hearing loss used oral communication (OC). They found that the language skills of the both the cochlear implant group and hearing aid group were "at about half to 2/3 of the normal rate on average" (p.274).

Fagan et al. (2007) carried out the only other study that has focused on children using a cochlear implant and OC. Fagan et al used the Peabody Picture Vocabulary Test-III (Dunn & Dunn, 1997) to measure receptive vocabulary. They found that the group mean receptive vocabulary standard score (80.5) of 26 children using a cochlear implant was below the normal range for children with normal hearing.

The results of the studies by Blamey et al. (2001) and Fagan et al. (2007) indicate that even when participants are limited to children using a cochlear implant and oral communication, the language outcomes are delayed when compared to typically developing hearing peers.

1.2.4. <u>READING OUTCOMES</u>

Success in reading requires the skill to blend together sequences of letters to make words, to be able to quickly recognize familiar words, as well as the skill to understand the meaning of the written words when connected together. These skills are essential for becoming a competent reader. Research into reading outcomes has focused on one or more of these skills. Any discussion about reading outcomes therefore needs to specify which reading skill is being discussed.

In this thesis reading outcomes are discussed in terms of *word reading* and *reading comprehension*. Word reading refers to the ability to convert a printed word into a form that may be spoken. The general term *word reading* in this thesis encompasses both real word reading (sight word reading) and nonword reading (phonemic decoding). While, *reading comprehension* describes the ability to discern meaning from written text. The term 'word (level) reading' (Snowling, 2005; Wagner, Torgesen, Rashotte, Hecht, Barker, Burgess, Donahue, & Garon, 1997) has been used interchangeably with 'word recognition' (Catts & Kamhi, 2005; Gillon, 2004; Larrivee & Catts, 1999; Wagner et al., 1993) and 'decoding' (Hoover & Gough, 1990; Nation, 2005). Word recognition is the more commonly used term in the literature (Catts & Kamhi, 2005; Gillon, 2004; Larrivee & Catts, 1999), but in this thesis the term word reading is used in order to avoid confusion with spoken word recognition, a topic also discussed in this thesis.

Success in reading requires mastery of both word reading and reading comprehension. While these two aspects of reading are distinguished it has been proposed there is a relationship between them. Hoover and Gough (1990) conducted a secondary analysis on the reading and listening comprehension results of 210 bilingual students to test predictions based around the *simple view of reading*[3]. They found that across Grades 1 to 4, "a substantial proportion of the variance in reading comprehension was accounted for by the linear combination of the decoding [word reading] and

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[3] The simple view of reading suggests that reading comprehension is the product of word reading and language comprehension (Hoover & Gough, 1990).

listening comprehension indices…However, the product of these two indices accounted for an additional significant proportion of variance" (pp.140 & 141). Other studies of children with normal hearing have also reported a relationship between reading comprehension outcomes and language skills (e.g., Catts, Adlof, & Ellis Weismer, 2006; Muter et al., 2004; Nation & M.J., 2004; NICHD, 2005; Roth, Speece, & Cooper, 2002a; Stothard & Hulme, 1992). Together these findings support the *simple view of reading,* that essentially reading comprehension is a product of word reading and language comprehension. While simple, this view of reading comprehension prompts the question of what underlies word reading?

There have been numerous studies conducted with children with normal hearing seeking to determine the underlying skills related to word reading (Griffiths & Snowling, 2002; Muter et al., 2004; Stothard & Hulme, 1995; Wagner et al., 1993). In general, the studies have focused on children's phonological processing abilities. For example, Muter et al. (2004) conducted a 2-year longitudinal study of spoken and written language abilities of 90 children beginning school. Muter et al found that reading comprehension was related to oral language abilities, in particular vocabulary as well as word reading, but that word reading was strongly predicted by letter knowledge and phonemic awareness not vocabulary and grammatical skills.

These studies point to the potential differences in performance on word reading versus reading comprehension tasks and the variables influencing these two aspects of reading. These findings suggest that both aspects (word reading and reading comprehension) should be investigated to measure reading abilities in children. The following section reviews research on the reading outcomes achieved by children with a significant hearing loss.

1.2.4.1. Reading Outcomes in Children with a Significant Hearing Loss

Early studies of children with a significant hearing loss found that by the time children left school, their achievements in reading were delayed relative to their hearing peers by up to 7 years (Conrad, 1979; King & Quigley, 1985; Quigley & Kretschmer, 1982). More recent studies suggest that this performance gap may have narrowed (Dalzell, Orlando, MacDonald, Berg, Bradley, Cacace, Campbell, DeCristofaro, Gravel, Greenberg, Gross, Pinheiro, Regan, Spivak, Stevens, & Prieve, 2000; Moeller, 2000; Thoutenhoofd, 2006) with some studies suggesting that cochlear implantation is associated with the improved outcomes (e.g., Spencer et al., 2003; Thoutenhoofd, 2006; Tomblin, Spencer, & Gantz, 2000). In children using hearing aids, better outcomes for reading have been linked with communication mode. These studies suggest that better reading outcomes are achieved in children who have been taught through an auditory-verbal (AV) approach (Robertson & Flexer, 1993), or those who have a combination of oral education, good use of residual hearing and a well-developed oral vocabulary (Geers & Moog, 1989).

Despite these improvements in reading outcomes, children with a significant hearing loss still do not typically achieve age appropriate reading skills (Harris & Beech, 1998; King & Quigley, 1985; LaSasso & Mobley, 1997; McAnnally et al., 1994; Paul, 1999). Holt et al. (1997) found that 926 high-school students with a significant hearing loss had a median reading comprehension score equivalent to a fourth grade reading level, indicating significant delay in reading. Geers and Moog (1989) investigated the reading skills of one hundred 16- and 17-year-old students who had a pre-lingual profound hearing loss, used hearing aids and OC. Only 34% of the participants scored in the normal range for their age on word reading, and only 30% did so for reading comprehension (text-level reading). Kaderavek and Pakulski (2007, p.69) point out that "the outlook for students with such a limited reading ability is not bright", linking the ability to read with academic success.

Robertson and Flexer (1993) hypothesised that because reading is based on oral language, children with a hearing loss who learn spoken language through audition, as in the auditory-verbal (AV) approach, will learn to read in a similar manner to children with normal hearing. They reported a study looking at the reading outcomes of children with a hearing loss taught through the AV method. Three hundred questionnaires were distributed to people potentially participating in an AV program, however only 76 questionaires were returned. Eighty one percent of the respondents had a significant hearing loss. Robertson and Flexer's data were based on a parent questionnaire that included questions about results on standardised reading tests. They found that 30 of 37 children that had been tested on reading measures standardised on children with normal hearing, had scores equivalent to or above the 50^{th} percentile, that is, they were able to achieve reading skills at or above those of their hearing peers. Given the low response rate, the authors acknowledge that the questionnaires may reflect only a select or biased group. Nevertheless, their results suggest that age-appropriate reading skills might be achievable, at least for some children with a significant hearing loss. This study was conducted before cochlear implants were widely used.

The increasing use of cochlear implants in children has been accompanied by an increased focus in the research on the outcomes of children fitted with these devices, including the outcomes for reading (Connor & Zwolan, 2004; Fagan et al., 2007; Geers, 2003; Spencer et al., 2003; Spencer, Tomblin, & Gantz, 1999; Vermeulen, van Bon, Schreuder, Knoors, & Snik, 2007). Spencer, Tomblin & Gantz (1999) measured the reading comprehension of 40 children using a cochlear implant and found that 54% of the children (21/40) were reading at or above Grade 4 level. However, when the results were analysed for grade equivalent reading outcomes, they found less than 25% of the children had reading comprehension at or above their grade level, while another 18% were less than 8 months below their grade level. This meant over half (57%) of the children had reading comprehension that was 12 months or more below their grade level. The majority of children (85%) in this study used simultaneous communication (i.e., simultaneous use of sign and speech, which does not necessitate the use of audition). Spencer et al did not report the implant model type or the processing strategy used by the children in the study.

A later study by Spencer et al. (2003) investigated the reading comprehension of 16 children using a cochlear implant and simultaneous communication. The cochlear implant group was significantly poorer on reading comprehension tasks than their age-matched peers with normal hearing. However, the cochlear implant group mean score was within the normal range for the standardised reading test (SS = 90.13) and the highest score from the cochlear implant group was above the normal range.

A series of studies by Geers and colleagues has reported on outcomes, including reading outcomes, of a large number of children using a cochlear implant (Geers, 2003; Geers et al., 2003a; Geers et al., 2003b; Pisoni & Cleary, 2003; Tobey et al., 2003). Geers (2003) reported that 52% of 181 cochlear implants users, aged 8 and 9 years, scored in the normal range on a total reading score that included measures of both word reading and reading comprehension. Reading comprehension was measured using a non-verbal multiple-choice task in which a sentence was read and the participant selected a corresponding picture from four response alternatives. The word reading task required the children to read a list of words. The children were in TC or OC programs, and were able to use either signed or spoken responses on the reading tasks. For both tasks testing was discontinued when a pre-determined number of consecutive incorrect responses were made, which indicates that the tasks were untimed.

Snowling (2005) argues that reading comprehension difficulties may be experienced when children are not fast and fluent in word reading, which suggests that untimed tasks may not accurately reflect the reading ability of children. Similarly, Joshi and Aaron (2002) in a study of children with normal hearing found that they could not identify children with slow word reading skills using an untimed task (the Word-Attack subtest of the Woodcock Language Proficiency Battery-Revised). These studies suggest that timed reading tasks are needed to investigate the efficiency of word reading and reading comprehension. Currently there are no studies using timed tasks to investigate the reading outcomes of children using a cochlear implant.

In a recent study Vermeulen et al. (2007) compared the reading comprehension and word reading outcomes of 50 children using a cochlear implant, 504 children who had a severe or profound hearing loss[4], and two groups of typically developing children with normal hearing[5]. Of the group using a cochlear implant a variety of communication modes were used by the 50 participants and less than half attended a mainstream school. Further 15 participants had been using the early M-PEAK coding strategy and the mean age of implantation was 74 months. The scores of the two groups of children with a hearing loss were compared in groups according to grade, but allocated on the basis of years of instruction rather than actual grade level; Group A = Years 1 to 3. In the

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[4] Vermeulen et al. describe this group as "almost all the deaf children and adolescents in The Netherlands" (pp 287 & 288), and indicated that not all these children used conventional hearing aids.
[5] Test norm data was used to compare the reading comprehension results with children with normal hearing. However 1,475 normal hearing children participating in another study were used to compare the visual word recognition scores with children with normal hearing.

reading comprehension task the children read a passage silently and then answered multiple-choice questions with the original text remaining available and no time limit for responses. The results showed that while the cochlear implant group was significantly better than the non-implant group on reading comprehension, their mean reading comprehension scores across grade groups were 3 to 4 standard deviations below the mean for typically developing children with an equivalent instructional age. The mean reading comprehension scores of the non-implant group were from around 3 standard deviations below the mean for children with normal hearing for the younger grade group increasing progressively to over 8 standard deviations below the mean for the oldest grade group. Vermeulen et al also used two lexical decision tasks to compare the visual word recognition skills of the three groups. Visual word recognition is a word reading task that involves "locating a familiar printed word in one's mental lexicon" (Coltheart, 2006, p.7). In the lexical decision task the children silently read the printed stimulus words and crossed out pseudowords (nonwords) from the list that contained both words and nonwords. This task measures children's lexical (orthographic) route of word reading. The results showed that the mean score for the non-implant group was only .60 below the mean for the children with normal hearing and there was no significant difference between the mean visual word recognition score (converted to z scores) of the cochlear implant group and the group with normal hearing. However, the cochlear implant group had a mean chronological age of 12.75 years, which was 2.65 years older than the group with normal hearing and Vermeulen et al did not include a group of age-peers with normal hearing to determine if the cochlear implant group were also performing at a level commensurate with their chronological age. Furthermore, this study did not examine the participants' ability to use a non-lexical or phonological route to word reading. The ability to utilise a phonological route is deemed necessary for skilled word reading in children with normal hearing (Ehri, 1995; Gillon, 2004; Share, 1995) and there is limited evidence that this is also true for children with a significant hearing loss not using a cochlear implant (Conrad, 1979; Musselman, 2000).

A recent investigation by Fagan et al. (2007) examined the reading outcomes of a group of 26 American children using a cochlear implant. All 26 participants were oral communicators, and were enrolled in mainstream education. Fagan et al. (2007) reported that the cochlear implant group mean score for reading (standard score of 96.1) was within the normal range. This reading score was based on combined performance on both word reading and reading comprehension tasks from the Peabody Individual Achievement Test – Revised (Markwardt, 1998). The participants' mean standard score for nonword reading was 101.0.

The results of the Fagan et al. (2007) study suggest that children using cochlear implants have reading scores commensurate with children with normal hearing. It is possible that the results of the children in this study were markedly better than any other reports of reading outcomes of children using a cochlear implant (e.g.,Geers, 2003; Spencer et al., 1998; Vermeulen et al., 2007) because of the characteristics of the participant group; Fagan et al used a cohort that was homogenous for communication mode and education setting. However, other research design factors may also account for the difference. For example, the reading comprehension test used in the Fagan et al study was a sentence comprehension test and the results were reported in conjunction with the word reading results, whereas the Vermeulen et al. (2007) study used a reading comprehension test that required the comprehension of passage length written material. The results of the Fagan et al study in particular are promising and suggest that further, more detailed investigation into the reading outcomes and associated abilities of children who use a cochlear implant are needed to establish whether age-appropriate reading outcomes are achievable, and under what conditions for children using a cochlear implant.

1.2.5. Reading and Language

The ability to read and the ability to understand and use language are both complex skills. Together, they have a complex relationship. It has been established in children with normal hearing that there is a relationship between reading comprehension and oral language skills (e.g., Catts et al., 2006; Catts, Fey, Zhang, & Tomblin, 1999; Nation, Clarke, Marshall, & Durand, 2004; Nation & M.J., 2004; Roth et al., 2002a). Reading outcomes have also been related to language ability (vocabulary and broader language) for children using a cochlear implant (Connor & Zwolan, 2004; Geers, 2003; Spencer et al., 2003; Vermeulen et al., 2007). However, this body of research has included children who use TC as well as children who use OC and some studies have used a composite word reading/reading comprehension measure. It is possible that the relationship between language and reading *comprehension* is different for different populations of cochlear implant users; those that are oral communicators who are more dependent on the processing of spoken language and those that use more visual based communication systems.

There is one known study that has reported on the reading and an aspect of language of oral communicating children using a cochlear implant. However, this study used an overall measure of reading rather than specifically looking at reading comprehension. Fagan et al. (2007) in the study reviewed in the previous section, reported that an overall reading measure (word reading and reading comprehension) was strongly related to receptive vocabulary (r = .76). The issue of whether broader (receptive and expressive) language skills are related to reading comprehension in a group of oral communicating children who use a cochlear implant is yet to be explored.

1.2.6. Summary

In summary, the literature reviewed in this section has shown that while some children with a significant hearing loss can achieve reading outcomes equivalent to their peers with normal hearing, many do not. There are indications that cochlear implant use may be associated with improved outcomes. There is great variability in reading outcomes achieved by children using a cochlear implant both within a group of participants and across studies, with at least some children achieving at or above the level of their peers with normal hearing. However caution is needed in interpreting these results because inclusion criteria of many studies do not specify communication mode, there has been a failure to test or report on the different aspects of word reading (sight word and phonemic decoding) and reading comprehension outcomes within the same study, and there have been different specifications of normal comparison (i.e., age vs grade equivalence). In addition, the rapid and significant technological changes in the cochlear implant indicate the need to specify the type of device used by children being studied and age at which they received their device.

There is an emerging body of literature that has investigated factors that are related to the large individual differences in outcomes (e.g., Blamey et al., 2001; Connor & Zwolan, 2004; Geers, 2003; Hammes, Novak, Rotz, Willis, Edmondson, & Thomas, 2002; Kirk, Miyamoto, Lento, Ying, O'Neill, & Fears, 2002a; Tobey et al., 2003; Tomblin et al., 1999). A number of researchers have argued that various factors such as age at implantation and length of cochlear implant use, affect outcomes in speech perception, speech production, language and reading of these children. In an effort to further understand the issue of variability, the following section reviews literature that has identified factors affecting the outcomes of children using a cochlear implant.

1.3. Factors Affecting Outcomes of Children Using a Cochlear Implant

Summerfield & Marshall (1999) argue that the improved auditory receptive capabilities provided by a cochlear implant to children with a significant hearing loss will form the basis of later benefits in spoken communication skills, educational achievements, social independence, and quality of life. While it is possible to assess the effectiveness of cochlear implantation in children in each of these areas, in practice, there are practical limitations on the type of research that can be done. There were significant developments in both implant technology and in hearing loss identification in the 1990s and so today there are still too few early identified and implanted children who have reached adolescence and adulthood to allow outcome studies with statistical power across the entire range of skills. However, the above review indicates that there is an emerging body of evidence from research studies that have focused on short- and medium-term outcomes within a few years of implantation to demonstrate some of the benefits of cochlear implantation such as improvements in speech perception (e.g., Blamey et al., 2001; Osberger, Miyamoto, Zimmerman-Phillips, & al., 1991; Staller, Beiter, Brimacombe, Mecklenberg, & Arndt, 1991; Tyler, Fryauf-Bertschy, Kelsay, Gantz, Woodworth, & Parkinson, 1997) and speech production (Tobey et al., 2003).

Many of the studies reviewed have found that not only is there wide variability in the outcomes for children with implants (Blamey et al., 2001; Flynn, 2003; Miyamoto et al., 1997; Waltzman, 2000), but that as a group they perform below their peers with normal hearing on speech perception and speech production (Blamey et al., 2001; Connor, Hieber, Arts, & Zwolan, 2000b), receptive and expressive language (Blamey et al., 2001; Geers et al., 2003b) and reading (Connor et al., 2000b; Geers, 2003; Spencer et al., 1999; Vermeulen et al., 2007) tasks. These results suggest that while cochlear implants deliver gains across a range of areas, the amount of gain may be impacted by other factors, leading to considerable variability in the outcomes achieved.

The following section summarises findings regarding demographic, implant-related and communication/educational factors that have been investigated to determine their relationship to speech perception, speech production, language and reading outcomes in children using a cochlear implant.

1.3.1. Factors That Impact on Cochlear Implant Outcomes

Research has investigated the impact of a range of factors on cochlear implant outcomes. To date, no single factor has emerged to account for the variability in outcomes. Studies have identified factors such as age at implantation and length of implant use (Connor & Zwolan, 2004; Dawson et al., 1995; Hammes et al., 2002; Kirk et al., 2002a), as well as length of deafness (Dawson et al., 1995), pre-implant hearing thresholds, and the type of implant or the speech processing strategy used in the implant (Dowell et al., 2002). Other studies have focused on communication mode (Connor et al., 2000b; Connor & Zwolan, 2004), and more debated factors such as gender, family factors (Connor & Zwolan, 2004; Geers, 2003; Geers et al., 2003a; Geers et al., 2003b).

1.3.1.1. Age of Implantation

Studies have compared outcomes for early versus late implanted children and found that earlier implantation is associated with better outcomes for speech perception (Dowell et al., 2002; Hammes et al., 2002), speech production (Connor & Zwolan, 2004; Geers, 2003; Tye-Murray et al., 1995), language (Connor & Zwolan, 2004; Dettman, Pinder, Briggs, Dowell, & Leigh, 2007; Hammes et al., 2002; Kirk et al., 2002a) and reading (Connor & Zwolan, 2004). However, a series of outcome studies reported by Geers and others found no significant relationship between age at implantation and outcomes for speech perception (Geers et al., 2003a), language (Geers et al., 2003b) and reading (Geers, 2003) in children who were all implanted before 5 ½ years of age. Geers (2004) further analysed the results of the children who were congenitally deaf and had an IQ above 80 (n=133). She found no significant correlations between age at implantation and outcomes for children between the ages of 2 to 4 years, however a larger percentage of the children receiving a cochlear implant at 2 years of age achieved speech and language skills within the normal range than children implanted at 4 years of age. Although it seemed that receiving a cochlear implant between the ages of 2 and 4 years was not related to more positive outcomes, Geers commented that perhaps implantation before 2 years of age would result in better outcomes.

1.3.1.2. Length of Cochlear Implant Use

The length of time a child has used a cochlear implant has been both positively and negatively associated with speech and language outcomes. Tomblin et al. (1999) found expressive language skills, measured by sentence complexity in a story retell task, were better in children with a cochlear implant compared to children wearing hearing aids, and that better expressive language outcomes were associated with length of implant use. This study suggests that children who have used their cochlear implant for longer have increasingly better scores than children with a profound hearing loss wearing hearing aids.

Studies have also investigated the impact of length of implant use on reading outcomes (Connor & Zwolan, 2004; Geers, 2003). Connor and Zwolan (2004) found that longer use of a cochlear implant was associated with poorer reading outcomes relative to peers with normal hearing. While Geers (2003) looked specifically at length of use with the SPECTRA processor with the SPEAK processing strategy, as opposed to overall length of implant use, Geers found improved reading outcomes relative to normal hearing peers with longer use of the SPECTRA.

Communication skills improve with increasing age in the general population (Fenson et al., 2000), the hearing-impaired population (Blamey et al., 2001), and the implanted population (Blamey et al., 2001; Svirsky et al., 2000). Investigations of length of implant use will interact with chronological age. In the Geers (2003) study even though grade equivalent and standard scores were reported and the children in the study were either 8 or 9 years of age thereby only differing in age by one year, Geers reported that chronological age was a significant predictor of reading outcomes. Therefore the positive relationship of length of use with SPEAK and reading outcomes may be confounded by the age of the participants.

1.3.1.3. Mode of Communication

Studies in the UK have reported that the use of cochlear implants in children has been associated with a shift towards a mainstream education (Archbold, Nikolopoulos, Lutman, & O'Donoghue, 2002; Fortnum, Marshall, Bamford, & Summerfield, 2002). Fortnum et al. (2002) reported that a higher proportion of UK children with cochlear implants were in oral education programs, compared to non-implanted children with profound hearing loss. Archbold et al. (2002) reported that the percentage of children with implants in oral education increases as a function of time after implantation. No similar studies exist for Australian children.

There are a number of options for mode of communication for children with a hearing loss (for a review see Gravel & O'Gara, 2003), with the main difference between approaches being the degree of reliance on audition. The communication approaches can be viewed along a continuum from the use of audition as non-essential to essential (see Figure 1.1) with heavier emphasis on audition in oral approaches (cued speech, auditory-oral and auditory-verbal).

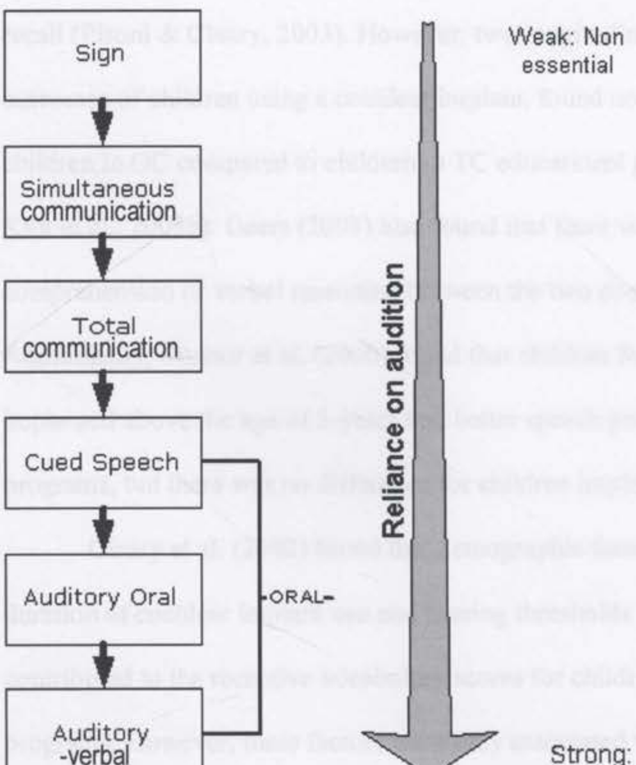

Figure 1-1 Approaches to communication development

The influence of communication mode on outcomes of children with a hearing loss has been frequently explored in the research (Cleary, Dillon, & Pisoni, 2002;

Connor et al., 2000b; Dillon & Pisoni, 2006; Geers, 2003; Geers et al., 2003a; Geers et al., 2003b; Kirk et al., 2002b; Pisoni & Cleary, 2003). Geers & Moog (1992) looked at the speech perception and production skills of 227 children educated in either an oral communication (OC) or total communication (TC) setting. They found that children who were educated in an OC setting had better speech perception and production skills than the children from TC settings.

Studies of children using a cochlear implant have also suggested that OC is associated with better outcomes in speech perception (Geers et al., 2003a), speech production (Tobey et al., 2003), narrative ability (Geers et al., 2003b) and digit span recall (Pisoni & Cleary, 2003). However, two longitudinal studies, focused on language outcomes of children using a cochlear implant, found no significant differences between children in OC compared to children in TC educational programs (Connor et al., 2000b; Kirk et al., 2002b). Geers (2003) also found that there was no difference in the language comprehension or verbal reasoning between the two communication groups. Additionally, Connor et al. (2000) found that children from OC programs who were implanted above the age of 5-years had better speech production than children in TC programs, but there was no difference for children implanted under 5 years of age.

Cleary et al. (2002) found that demographic factors such as age at implantation, duration of cochlear implant use and hearing thresholds prior to cochlear implantation contributed to the receptive vocabulary scores for children in both OC programs and TC programs. However, these factors were only associated with open-set speech perception in the children using OC.

Mode of communication (OC versus TC) has not been associated with reading outcomes (Connor & Zwolan, 2004; Geers, 2003). However, Geers (2003) found a significant effect for educational placement, with children in a mainstream class having significantly better reading outcomes than children in a special education class.

Under the umbrella of an *oral* approach there are several educational approaches that have different degrees of emphasis on speech and auditory development (see Figure 1.1). In an overview of a series of studies Moog and Geers (2003, p.124S) concluded "the dominant educational factor associated with high performance levels was the extent to which a child's classroom communication mode emphasized speech and auditory skill development". Geers (2003) classified children as *oral communicators* based on the emphasis in their educational program on speech and auditory development. Cued speech was assessed as having least emphasis, auditory-oral having medium emphasis and auditory-verbal (AV) having the greatest emphasis. Kaderavek and Pakulski (2007) speculate that children who have developed oral communication following an AV approach may achieve better reading outcomes than from other modes of communication, due to the AV intervention practices that promote emergent literacy practices as well as targeting aspects of phonological awareness. However to date there is no evidence regarding the reading skills of children using a cochlear implant who have received AVT.

Two studies that have investigated the language outcomes of children in AV programs have included participants with a range of hearing losses using either hearing aids and/or cochlear implants (Dornan, Hickson, Murdoch, & Houston, 2007; Rhoades & Chisolm, 2002). Although the participants in these studies were not limited to cochlear implant users or children with a significant hearing loss, the findings indicated that children who receive AVT develop language at a rate commensurate with their hearing peers. However, Dowell et al. (1995) have questioned any causal relationship between mode of communication and outcomes. They point out that the outcomes may be a result of the criteria used to select a mode of communication for a child. That is, children may be in oral-only programs because they had better oral skills or were assessed as having the potential to develop those skills.

Generalisations and conclusions about mode of communication are also difficult because the implementation of each mode of communication will vary in terms of the quality and quantity of both spoken and signed language interactions. While AV programs have specific certification requirements that may aid uniform understanding of teaching practices, this does not apply to other modes of communication. For example, while TC programs use a mixture of sign and oral language, there is no shared understanding about how this is done, and teachers may have widely divergent practices depending on the perceived ability of individual children.

1.3.1.4. Pre-implant Hearing Thresholds

The influence of pre-implant hearing thresholds, often reported as Pure Tone Average (PTA), on post-implant performance is inconclusive. Blamey et al. (2001) found no significant relationship between pre-implant PTA and rate of language development. Further, a significant negative correlation between PTA and speech perception outcomes found by Blamey et al. (2001) was explained by the speech production and language outcomes. Whereas, Connor & Zwolan (2000) found that higher preoperative aided speech detection thresholds where associated with speech production and expressive vocabulary, but not with receptive vocabulary.

1.3.1.5. Gender

The influence of gender on outcomes of children using a cochlear implant is also inconclusive. Geers and colleagues found that girls performed better than boys on measures of speech production (Tobey et al., 2003), language (Geers et al., 2003b) and reading (Geers, 2003), but not speech perception (Geers et al., 2003a). However, Dillon and Pisoni (2006) found that there was no significant difference in the performance of boys and girls on reading tasks. Connor and Zwolan (2004) also reported that gender was not related to the reading comprehension outcomes of children using a cochlear implant.

1.3.1.6. Family Factors

Socio-economic status (SES) has been associated with better outcomes in children using a cochlear implant (Connor & Zwolan, 2004; Geers, 2003). Studies have reported that children from families of higher SES achieve higher reading scores than those from lower SES (Connor & Zwolan, 2004; Geers, 2003).

In children with normal hearing, parent's SES and maternal characteristics have been found to be related to language outcomes (Hoff & Tian, 2005; Yoder & Warren, 2001). In the field of cochlear implantation, studies have only recently begun to emerge investigating factors regarding the parent's influence over their child's communication development. DesJardin & Eisenberg (2007) explored the impact of maternal factors on the language skills of a child using a cochlear implant. In a group of families of middle to high SES, they found that a mother's mean-length-of-utterance (MLU) and facilitative language techniques such as use of recasts and open-ended questions were positively associated with the language skills of children using a cochlear implant.

Geers and colleagues investigated the effect of family size on the outcomes of children using a cochlear implant and found that children from smaller families had better outcomes in speech perception, speech production and language (Moog & Geers, 2003), but not reading (Geers, 2003).

1.3.1.7. *Type of Implant*

The first multi-channel cochlear implant operation on a child was performed at the Bionic Ear Institute in Melbourne in 1985 by Professor Clark (Clark, 1997). In 1990 the Nucleus cochlear implant was approved by the Therapeutic Goods Administration, for clinical use with children aged 2 years and older and in 1999 for children aged 12 months.

Since the first child received a multi-channel cochlear implant there have been significant advances in all aspects of the implant design (internal and external) that have improved the quality of auditory information that users receive from the cochlear implant (Clark, 1997, 2006; Flynn, 2003; Waltzman, 2000). The most significant advances were the introduction of the SPEAK speech coding strategy in 1994 (Clark, 2006) and the first major change in the internal implanted electrode array in 1996, which enabled the use of higher stimulation rates in speech processing strategies such as ACE (Vandali, Whitford, Plant, & Clark, 2000).

Recipients with early model cochlear implants and programming strategies were often only able to discern elementary speech information such as number of syllables and they required additional visual input for communication (Waltzman, 2000). Studies have consistently found improved speech perception results with participants using SPEAK rather than the earlier MPEAK processing strategy (Cowan, Brown, Whitford, Galvin, Sarant, Barker, Shaw, King, Skok, Seligman, & al., 1995; Dowell et al., 2002; Skinner, Clark, Whitford, Seligman, Staller, Shipp, Shallop, Everingham, Menapace, Arndt, Antognelli, Brimacombe, Pijl, Daniels, George, McDermott, & Bieter, 1994; Whitford, Seligman, Everingham, Antognelli, Skok, Hollow, Plant, Gerin, Staller, McDermott, Gibson, & Clark, 1995). For example, Cowan et al. (1995) found that the speech perception results of 11 out of 12 children significantly improved when changed from the MPEAK to the SPEAK processing strategy using the Nuclues® 22 device. However, the differences in outcomes with the more current devices (Nucleus® 22 versus Nucleus® 24) and strategies (SPEAK and ACE) are not as conclusive. In a study of 7 children, Psarros et al. (2002) reported a small but significant improvement in the speech perception scores when the children using the Nucleus® 24 device changed from the SPEAK to ACE processing strategy. However, not all children showed this improvement.

Overall, there are few studies exploring predictive factors associated with reading outcomes in children using a cochlear implant, and only two that report on the relationship of implant-related factors and reading outcomes. In both these studies a large proportion of the participants used the earlier MPEAK processing strategy before converting to the later SPEAK processing strategy (Connor & Zwolan, 2004; Geers, 2003). Geers (2003) reported that 69% of the children in her study (124/181) initially used the MSP processor with the MPEAK coding strategy while only 30% of the children (55 /181) initially received the Nucleus ® 22 device with the SPEAK processing strategy. Geers (2003) found that duration using the Nucleus® 22 processor with the SPEAK strategy, as opposed to the earlier implant device with the MPEAK strategy, and average dynamic range significantly contributed to the variance in reading outcomes. Conversely, Connor and Zwolan (2004, p.512), reported that "length of time with SPEAK did not significantly predict reading comprehension".

1.3.2. SUMMARY

Research on the outcomes of children using a cochlear implant has largely focused on three areas: speech perception, speech production and language outcomes.

Together this research suggests that the increased access to auditory information provided by the cochlear implant is showing the cascade effect proposed by Summerfield and Marshall (1999). That is, improved auditory input has been associated with improved speech and language outcomes. Recently information on the reading outcomes of children using a cochlear implant has begun to emerge. Preliminary research suggests that the reading outcomes of children using a cochlear implant are better than those of children with a profound hearing loss without a cochlear implant (Vermeulen et al., 2007), but are still worse than their grade-equivalent peers with normal hearing (Geers, 2003; Spencer et al., 1999). There have also been reports of large ranges in outcomes ranging from below to above the hearing average both within a group of participants and across studies (Fagan et al., 2007; Geers, 2003; Spencer et al., 2003; Spencer et al., 1999; Vermeulen et al., 2007).

Short- and medium-term outcomes of cochlear implantation have been associated with a range of factors and this research suggests the need for more controlled studies. For example, research on reading outcomes in children using a cochlear implant have included a large proportion of participants who were initially mapped with the MPEAK processing strategy (Connor & Zwolan, 2004; Geers, 2003; Vermeulen et al., 2007) and have included participants that have either used a variety of communication modes (Connor & Zwolan, 2004; Geers, 2003; Vermeulen et al., 2007) or have predominantly used simultaneous communication (Spencer et al., 2003; Spencer et al., 1999). In addition, most of the reading outcome research has focused solely on reading comprehension or have reported a combined word reading and reading comprehension score. The separate contributions of reading comprehension and word reading have not been adequately addressed. Moreover, there has been no research to date exploring word reading *efficiency* abilities in children using a cochlear implant.

This review suggests that research on reading outcomes needs to better control and account for variables known to contribute to reading outcomes, and needs to examine specific hypotheses about the relationship of improved auditory input and later outcomes, especially for reading. Further, factors contributing to reading outcomes need to be explored. There is a need to include specific hypotheses about skills that may contribute to reading outcomes in children using a cochlear implant. To adequately develop these hypotheses the large body of literature on this topic in children with normal hearing needs to be examined.

Snowling and Hayiou-Thomas (2006, p.117) when referring to children with normal hearing state "The widespread consensus in the field is that phonological processes play a key role in learning to read". Previous research has established a strong relationship between reading performance and different components of phonological processing in children with normal hearing (e.g., Catts & Kamhi, 2005; Griffiths & Snowling, 2001; Stackhouse & Wells, 1997; Wagner et al., 1993; Wagner et al., 1997). Typically, researchers have studied children with reading difficulties, predominantly word reading difficulties, and examined their phonological processing abilities. The findings suggest that, regardless of IQ, children with reading difficulties have deficient phonological processing abilities (e.g., Elbro, Borstrom, & Klint Petersen, 1998; Griffiths & Snowling, 2002; Snowling & Hayiou-Thomas, 2006; Swan & Goswami, 1997b; Wagner et al., 1997). Phonological processing ability has also been linked to speech perception (Breier, Fletcher, Denton, & Gray, 2004; McBride-Chang, 1995; Rvachew & Grawburg, 2006), speech production and language skills (e.g., Adams & Gathercole, 1995, 2000; Bird, Bishop, & Freeman, 1995; Larrivee & Catts, 1999; Leitao, Hogben, & Fletcher, 1997; Montgomery, 2002; Sutherland & Gillon, 2005; Weismer, J.B., Zhang, Buckwalter, Chynoweth, & Jones, 2000).

The cochlear implant provides children with a significant hearing loss the opportunity to engage in phonological processing. Subsequently, recent research involving children who use a cochlear implant has begun to explore the nature of their phonological processing abilities and how they might influence reading outcomes. However, relative to the large body of information about these abilities in children with normal hearing, very few studies have examined the phonological processing abilities of children using a cochlear implant.

In the following chapter, the literature regarding children with normal hearing is reviewed to define and describe phonological processing. The review of this literature then provides background and justification for exploring the phonological processing abilities and relationship of phonological processing to reading outcomes in children who use a cochlear implant.

Chapter 2. Phonological Processing and Reading

This chapter explores the increasing evidence about the important roles that phonological processing play in both written and spoken language. Phonological processing is a generic term for cognitive operations used in spoken and written language at an elemental level (i.e., at a phonological level, in contrast to processes that occur at syntactical and semantic levels) (e.g., Catts, 1989; Catts & Kamhi, 2005; Gillon, 2004; Passenger et al., 2000; Stackhouse & Wells, 1997; Wagner et al., 1993).

Most research into phonological processing is based on three distinct but related abilities. Based on the work by Wagner, Torgesen and Rashotte et al. (1997) these include:

- Phonological Awareness - the explicit awareness of the sound structure of one's oral language.
- Phonological Working Memory - the encoding and temporary storage of spoken information.
- Phonological Retrieval (also known as phonological naming or rapid naming) - the ability to quickly access and retrieve a phonological representation from long-term memory.

In the sense that phonological processing is hypothesised to underlie a range of spoken language and reading skills it is also necessary to note that the encoding of speech into phonological representations is initially dependent on speech perception skills during speech and language acquisition (Rvachew & Grawburg, 2006). The relevance of this issue for children using a cochlear implant was summarized by Geers

(2003, p.59S) who specifically hypothesised "that the improved speech perception abilities acquired with cochlear implantation would promote phonological coding skills and facilitate the acquisition of beginning reading skills." In other words the benefits that would come from the integration of improved speech perception with language development would lead to improved phonological processing that would produce enhanced skills in word reading.

To illustrate the link between written and spoken language the following provides an overview of the dominant theoretical concepts associated with spoken and written word processing, including the concept of phonological representations. The implications of a hearing loss on spoken and written word processing are considered. This is followed by a detailed review of the literature on each phonological processing concept including: phonological working memory, phonological awareness and phonological retrieval in children with normal hearing and children with a hearing loss.

2.1. Spoken Word Processing

The processing of a spoken word can be either implicit or explicit. For example, being able to discriminate 'cat' versus 'hat' as different from one another based on segmental information can be carried out implicitly without conscious thought. The process by which children store the phonological aspects of words into their lexicon is termed phonological encoding. Catts (1989, p.102) described the process of phonological encoding as "perceptually analysing the speech signal, deriving the phonological structure of words, and storing the phonological representations or names in long-term memory or semantic memory". The establishment of phonological representations is the product of the encoding process. When a child hears a single word they go through a process of *encoding* where the segmental and suprasegmental features of the word are analysed and the sounds are given a phonetic representation (Catts & Kamhi, 2005). The phonetic representations are then encoded with the assistance of working memory and given a phonological representation in the lexicon (Catts & Kamhi, 2005); this is generally carried out implicitly without much cognitive attention being given to the process.

The task of reading via a phonological route however, requires an explicit awareness of the phonological structure of the language so that sounds can be matched to the grapheme representing that sound visually (Catts & Kamhi, 2005). There is strong evidence that phonological awareness ability is related to reading ability (e.g., Ehri, Nunes, Willows, Valeska Schuster, Yaghoub-Zadeh, & Shanahan, 2001; Gillon, 2005; Metsala, 1999; Muter et al., 2004; Rvachew & Grawburg, 2006; Wagner et al., 1997). However, children with reading difficulties are also reported to experience difficulties in a number of areas that are based on the processing of phonological information, such as learning new words (Baddeley, Gathercole, & Papagno, 1998; Gathercole, 2006; Gathercole, Hitch, Service, & Martin, 1997) and accurately naming pictures (Bird et al., 1995; Elbro et al., 1998; Katz, 1986; Swan & Goswami, 1997b). These results are consistent with the view that a number of children with word reading difficulties such as dyslexia have a core deficit in the quality of their phonological representations in memory. Aparicio, Gounot, Demont and Metz-Lutz et al. (2007, p.1305) state, "Well-specified phonological representations are necessary to master the rules of grapheme-to-phoneme conversion, and especially to develop phonological word form representations relevant to the direct route of reading favoured by expert readers."

2.1.1. PHONOLOGICAL REPRESENTATIONS IN THE LEXICON

In an attempt to try and understand how words in our vocabularies are stored, words have been envisaged as containing different but connected types of representations (e.g., phonological, semantic, syntactical). The phonological representations are conceived to be a long-term store in which the phonological aspects of words are stored (Stackhouse, Vance, Pascoe, & Wells, 2007; Sutherland & Gillon, 2005). This store is construed to have links with semantic representations of words that together (with other representations such as grammatical) form the lexicon. The levels to which stored phonological representations are specified are thought to vary. It has been suggested that these representations could be large units such as whole words or even phrases, or finer segmental units containing phonetic detail (Anthony & Lonigan, 2004; Sutherland & Gillon, 2005). In young children phonological representations are thought to be initially less precise and in larger units (Jusczyk, 1992; Walley, Metsala, & Garlock, 2003). Very young infants with normal hearing can discriminate phonetic distinctions (Eimas, 1985; Jusczyk & Luce, 2002), however it is thought that repeated exposures to their specific language are required for the speech signal to be categorically encoded and organised within the their phonological lexicon. The literature regarding theories about the nature and robustness of phonological representations is tentative[6]. These phonological representations are thought to be abstract enough to enable recognition of words with different speakers, but specific enough to enable differentiation with other words (Munson, 2006; Stackhouse & Wells, 1997). The nature of phonological representations in memory could be influenced by the level of memory that needs to be employed (either short- or long-term storage), as well as by the task requirements that are used to demonstrate phonological processing. Some researchers focus on phonological representations in long-term memory, or the available lexicon of the participant, whereas others discuss the quality and retention of phonological representations in working memory that could also include items, such as nonsense syllables that have no long-term representation. Although it is possible that a general difficulty with the specification of phonological representations can occur both within working memory and within the lexicon, it is also likely that these two levels of storage (temporary and long term) could be differentiated as well as highly interactive.

Metsala (1997) investigated the spoken word identification, phonological awareness and nonword reading abilities of 39 children with poor reading skills and 61

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[6] Munson (2006, p.579) points out that there can be both word specific representations as well as abstract representations inferred from the "abstract phonological categories of the ambient language". However in the larger body of literature studies tend to focus on either the specification of phonological representations in the lexicon (Sutherland & Gillon, 2005; Elbro et al., 1998) or the encoding and/or temporary storage of phonological representations in working memory (Montgomery & Windsor, 2007; Gathercole, 2006; Gathercole et al., 1997). It is possible that difficulty with specification of phonological representations can occur both within working memory and within the lexicon. While there is evidence to support that these two types of storage (temporary and long term) can be differentiated and that phonological working memory should not just been viewed as a system of long-term memory (see Baddeley et al., 1998), it is also likely that they are related. Gathercole (2006, p.519) states "although the [phonological working memory] is considered to be a storage device that is distinct from stored lexical phonological knowledge, it does not operate in isolation from more permanent knowledge representations. Immediate memory performance is strongly influenced by the lexical characteristics of the memory stimuli; serial recall is superior for words than nonwords and for words with high than low frequencies." In this thesis, for ease of discussing different studies that have focused on different aspects of storage; temporary or long term, a distinction is made between specification of phonological representations within the long term memory (lexicon) and temporary encoding and endurance of phonological representations in short term memory (phonological working memory).

children with normal reading skills. Metsala used a gating task in which the participants heard increasing amounts of the word until identification as a measure of spoken word identification. He found that the children with poor reading acted much like younger children in that they needed more speech input to identify words with few similarly sounding neighbours, but not for those words within dense lexical neighbourhoods, suggesting their lexical representations are immature and less distinct. Metsala also reported that for the youngest third of participants, spoken word recognition "predicted unique variance in word reading even after variance due to age, vocabulary and phonological awareness were accounted for" (p.164). In this study it was found that age was a factor in the amount of speech input required for recognition of words suggesting that younger children need more information to identify words than older children. These and other findings led Walley and Metsala (1998) to propose the Lexical Restructuring Model (see Walley et al., 2003) to describe the development of phonological representations. There are four basic claims to this model, two which can be summarized as suggesting that younger children's lexical phonological representation are in larger more holistic units, but that these representations are required to narrow and become organized segmentally (phonemically) for vocabulary growth (Griffiths & Snowling, 2001; Metsala, 1997; Walley et al., 2003). According to this model segmental restructuring of the phonological representations is required before phoneme awareness can develop.

The quality of phonological representations is difficult to specifically measure because of their perceived central position in speech processing. Some researchers have used specific tasks to measure phonological representations such as phonological distinctness task (Elbro et al., 1998; Foy & Mann, 2001) or gating paradigm tasks (Griffiths & Snowling, 2001; Metsala, 1997). For example, Elbro et al. (1998) used a 'phonological distinctness' task in which children were required to teach a puppet the correct pronunciation of a word (usually polysyllabic) produced incorrectly by the puppet in response to picture stimuli. However success on such tasks will also be affected by input and output operations including speech perception or speech production difficulties. Alternatively the quality of a child's phonological representations may be hypothesised given outcomes from multiple measures that utilize phonological representations (Fowler & Swainson, 2004; Foy & Mann, 2001; Stackhouse et al., 2007). When a child has difficulty in a number of skills that utilize phonological information (e.g., phonological awareness, speech production, and naming) the quality of a child's phonological representations has been implicated. For instance, the underlying phonological representation has been assumed as lacking strength (Foy & Mann, 2001), specificity (Aparicio et al., 2007; Fowler & Swainson, 2004; Gillon, 2005; Griffiths & Snowling, 2002; Sutherland & Gillon, 2005; Swan & Goswami, 1997b) or distinctness (Elbro et al., 1998). For the purpose of this thesis a phonological representations deficit refers to Gillon's and others notion of the phonological representation being poorly specified.

If for some children the change to more segmental organisation is delayed and/or the representations do not become well specified, then other skill areas that draw upon the phonological representations might also be delayed or impaired. Children with normal hearing and word reading difficulties have been found to have deficits in other areas that also utilize phonological information such as phonological awareness, vocabulary, rapid automatized naming, and speech production leading to the hypothesis that the specification of their phonological representations may underlie the relationships (Elbro et al., 1998; Gillon, 2004; Leitao et al., 1997; Metsala, 1997; Swan & Goswami, 1997b).

Alternative theories to the popular theory of deficit phonological representations have been proposed to try and explain the relationship between phonological processing abilities and reading. One alternative theory is that a general auditory temporal processing difficulty underlies the relationship between phonological awareness and reading. Tallal (1980) conducted a study exploring the auditory temporal perceptual abilities of 20 children with reading difficulties between 8 to 12 years of age. Data on 12 children with normal reading skills from a previous study were used as a control group. Using nonspeech tones Tallal measured the children's ability to discriminate, and to sequence two tones at both a normal and rapid presentation rate. Tallal reported that the children with reading difficulties had significantly more difficulty sequencing the tones than the control group only in the rapid presentation condition. However, the case for a general auditory temporal processing difficulty in children as a cause of reading difficulties in normal hearing children is not strong (Brady, Shankweiler, & Mann, 1983; Bretherton & Holmes, 2003; Mody, Studdert-Kennedy, & Brady, 1997).

Children with reading difficulties seem to present with speech perception difficulties specific to speech stimuli (Brady et al., 1983; Mody et al., 1997). One theory arising from these findings is that underlying the difficulties in reading are difficulties in discriminating and encoding phonetic information in working memory (Mody et al., 1997). Other alternative theories include that the phonological representations are intact, but there is a difficulty with access to these representations during working memory and phonological awareness tasks (Ramus & Szenkovits, 2008), or that there are difficulties in the retrieval of phonological representations. For example, Griffiths and Snowling (2001) conducted a study to investigate the Lexical Restructuring Hypothesis. The participants included 29 children with dyslexia and two control groups: 14 children matched for age (CA) and 15 children matched for reading age (RA). Measures of nonword reading, rapid automatized naming and auditory word gating ability were obtained. These investigators adopted an auditory gating task similar to that used by Metsala (1997) with a few modifications, such as the presentation was length-blocked so that each of the participants responded to progressively longer gates. Griffiths and Snowling found that both children diagnosed with dyslexia and chronological age (CA) matched controls needed less acoustic input for word identification than reading age (RA) controls, but that the dyslexia group did not differ from the CA controls. Further, word identification times did not correlate with word or nonword reading whereas performance on rapid automatized naming tasks did. The finding of the Griffith and Snowling study were at odds with the findings of Metsala (1997) and led the researchers to suggest that children with reading difficulty (dyslexia) do have segmental phonological representations, but have difficulty with phonological retrieval.

However there is other evidence looking at a broader range of variables that suggests that difficulties in phonological retrieval tasks such as speech production may be due to difficulties with specification of phonological representations. Rvachew and Grawburg (2006) investigated the phonological awareness development of 95 normally hearing children with speech sound disorders. Two models of possible relationships between speech perception, articulation, receptive vocabulary, phonological awareness and emergent literacy knowledge were tested using linear structural equation analysis. The speech perception task in this study required the participants to identify whether or not words were articulated correctly by pointing to a picture if the word was correct (e.g., lake) and to an X if the word was not correct (e.g., wake). While the children do not need to be consciously aware of the sound segments to complete this task, they would access phonological representations (Rvachew & Grawburg, 2006) to make the judgement. As well as reflecting acoustic-phonetic encoding, performance on this task could be said to reflect the specification of phonological representations. Rvachew and Grawburg reported that the model of best fit in the analysis was the one in which performance on the speech perception and receptive vocabulary tasks determined phonological awareness performance. In turn phonological awareness performance explained a large proportion of the variance in emergent literacy knowledge. These findings provide support to the idea that children with speech disorders may have a common underlying factor at the level of phonological representations rather than with speech motor output.

In a hallmark study, Bird et al. (1995) investigated the phonological awareness and literacy skills of two groups of boys with a phonological impairment; 22 boys had an additional language impairment and 19 boys had no additional language problems. The skills of a control group of chronological age and IQ matched boys were also measured. Assessments were conducted at three time periods over 2 years. Bird et al found the phonological awareness scores of both groups of children with expressive phonological impairments were significantly below the control group at all assessment periods even when no speech output was required. They also found that the reading and spelling scores of children with expressive phonological impairments were significantly below those of the control group at all time periods, and the initial expressive phonology measure was significantly different for those grouped with either a good or poor literacy outcome on the third testing occasion. Instead of these speech production difficulties being the result of motor output deficit, Bird et al reflected that their findings suggest that the difficulties of children with expressive phonological impairment could be explained by difficulties with the categorization of speech segments, that is, difficulties in the underlying phonological representations.

There is evidence that polysyllabic word production is particularly discriminating of children with reading and/or phonological processing difficulties (Katz, 1986; Larrivee & Catts, 1999; Swan & Goswami, 1997b). For example, Swan and Goswami (1997) examined the picture naming and vocabulary skills of four groups of 16 children: those with dyslexia, garden-variety poor readers, chronological age-matched controls and reading age-matched controls. A picture naming task was administered which contained 20 monosyllabic words and 20 polysyllabic words. An object naming test using the words from the picture naming task and a receptive vocabulary test were also administered. They found that control groups were better at picture naming than the children with dyslexia and the garden-variety poor readers. However, the children with dyslexia had particular difficulty with the retrieval of picture names when the words were long in spite of these names being within their vocabularies. There was no effect of word length on the picture naming difficulties of the garden-variety poor readersThe picture naming errors made by the dyslexic children also contained significantly more phonological errors than other groups. Swan and Goswami concluded that the children with dyslexia might have a specific difficulty with the specification and/or retrieval of phonological representations.

In the Rvachew and Grawburg (2006) study there was no direct relationship of speech production and phonological awareness, however this may have been because the measure of speech production was an articulation test with few polysyllabic words and/or because all the children had a speech disorder there was not enough differentiation in speech production ability between the participants. Interestingly, Rvachew and Grawburg reported that, "speech perception had both a direct effect on phonological awareness and an indirect effect that was mediated by receptive vocabulary" (p.83). This indirect effect supports the Lexical Restructuring Hypothesis; vocabulary drives specification of phonological representations, and children with better-specified phonological representations should be better able to reflect on the segments in phonological awareness tasks. Although the children in the Rvachew and Grawburg study had *normal hearing*, the direct effect of speech perception performance on phonological awareness suggests children who are better at encoding acoustic-phonetic information also have better phonological awareness. These findings have implications for the establishment of phonological representations and subsequent development of phonological awareness in children with a hearing loss.

2.1.2. Spoken Word Processing: Implications for Children with a Hearing Loss

Children with a significant hearing loss do not have 'normal' auditory access to the speech signal. Poor speech perception skills are commonly reported in children with a significant hearing loss, even those using a cochlear implant. In children with normal hearing the cochlea has normal function before birth, reaching maturity after the 20th week of gestation, and to some extent from 20 weeks gestation an infant in-utero is exposed to their mother's language. The infant begins their perceptual learning to discriminate between sounds and then to categorically organize the sounds of the language to which they are exposed (Northern & Downs, 1984). Children with a pre-linguistic, significant hearing loss are therefore at a disadvantage from the beginning, in that the longer they are without access to the sounds of their native language the less opportunity they have to make sense of the phonological structure of their language.

Recent evidence suggests there may be an optimum period for auditory neural modification in the first few years of life (Sharma, Dorman, & Kral, 2005; Sharma, Dorman, & Spahr, 2002). Sharma, Dorman and Spahr (2002) conducted a study to measure the cortical responses of people with a congenital loss who were using a cochlear implant. They found that the latencies of the peaks of the first waveform were delayed in individuals who received their cochlear implants after 3.5 years compared to the latencies of children implanted before this age, and to people with normal hearing.

Eimas (1985, p.6) in reference to children with normal hearing suggests that "long before infants can speak and understand they are particularly sensitive to the acoustic distinctions crucial to the comprehension of speech". It is during this period in which the neural foundations are laid. Children with significant hearing loss are at risk for experiencing difficulties encoding an acoustic signal into a phonological form. Consequently, there is the possibility of a cascading effect. If all the acoustic information contained in speech that assists in the recognition of phonemes is not available (Burt, Holm, & Dodd, 1999; Catts & Kamhi, 2005; Gillon, 2004), they may have less accurate perceptual analysis (phonetic detection and discrimination) and therefore difficulties with phonological encoding and establishing well-specified phonological representations. According to the Lexical Restructuring Hypothesis, phonological representations become finer grained and segmental with vocabulary development, and consequently age. There are two possible reasons for children with a hearing loss being at risk for having poorly specified phonological representations for their age. Firstly, the speech signal that they receive is of poorer quality than children with normal hearing. Lower level perceptual difficulties are likely to effect the encoding of speech and make it more difficult for them to establish well-specified representations. Secondly, if vocabulary expansion drives the refinement of phonological representations, then the reduced oral vocabulary skills reported in children with a significant hearing loss (refer to chapter 1) present a risk to the establishment of well-specified representations for these children.

It is important to note that phonological development is not exclusively dependent on the auditory modality and to some extent the visual information, such as speech reading, is a source of information that may enable children with a significant hearing loss to develop phonological representations (Dodd & Hermelin, 1977; Transler, Gombert, & Leybaert, 2001). Dodd (1995) suggests that many children who are hearing-impaired develop phonological skills using their residual hearing, vision and touch. However, speech reading cannot provide all the information that is contained in an auditory signal of speech such as the suprasegmental features, voicing/nonvoicing cues, nasality and so forth, and the phonological information obtained via speech reading is likely to be poorer and less precise than via an auditory signal (Colin, 2007; Dodd & Hermelin, 1977; Transler et al., 2001). There is some evidence that teaching cued speech to children with a significant hearing loss facilitates the development of well-specified phonological representations and therefore phonological awareness (Charlier & Leybaert, 2000; Colin, 2007). But even children who have been taught cued speech have been found to have poorer rhyme awareness abilities than children with normal hearing (Colin, 2007).

The quality of phonological representations of children with hearing loss has rarely been discussed in the literature. There is some evidence that even children with a mild to moderate hearing loss have difficulties with the encoding process and in forming well-specified representations in working memory and subsequently the lexicon (Gilbertson & Kamhi, 1995). If implicit processing of phonological information is disrupted it is possible that developing explicit processing (phonological awareness) of the sounds of language may also be compromised. Thus it seems reasonable to suggest that children with a significant hearing loss, including those who use a cochlear implant, could be at risk of difficulties establishing well-specified phonological representations and consequently difficulties with phonological awareness and word reading.

2.2. Written Word Processing: Word Reading

There are various paths to learning to read including the use of *sight* words (identified by just their visual form), analogy, prediction or phonological recoding/decoding. The dual-route model of reading is a model that describes the possibility for single words to be read (i.e., access a semantic representation) either via a direct visual (orthographic) route or a phonological route (Coltheart, 2006; Kamhi & Catts, 2005). Semantic representations of written words can be accessed via matching a word's orthographic features with stored representations. However if a word does not have a stored representation, that is, it is a new or nonword, then a phonological route must be employed. For example if a child needs to read the word 'banana', they would look at the word (visual input), determine if there is a stored orthographic representation of that word, and if there is, access its stored lexical semantic and phonological representations. If the whole word is not recognized by sight, the child may then engage in phonological decoding, that is the process of grapheme-phoneme conversion. To do this children require knowledge of the letters matched to the sounds they represent. Children need to convert the letters or letter segments to a sound sequence. Then they use their working memory to retain the sequence of sounds and their phonological awareness abilities to pull sequence of sounds together. If the resulting sequence of sounds is recognized as a known word, the stored lexical phonological and semantic representations are accessed. If the word is a nonword the sequence of sounds may be temporarily held in working memory while a motor program is generated and the word may still be spoken without needing to access the lexicon. To keep the word active in phonological working memory the child might repeat the word silently to him or herself (subvocal rehearsal).

It has been proposed that "*skilled readers* [italics added] rely on the direct visual route when reading familiar text" (Gathercole & Baddeley, 1993, p.178), but that orthographic representations can be acquired either via direct instruction (i.e. rote learned) or with repetition of the same phoneme-grapheme conversion (i.e. via a phonological route) (Share, 1995). Ehri (1995) proposed that in the very early stage of learning to read, word meanings are accessed via visual features of a written word (pre-alphabetic phase), and then through partial phonological recoding (partial alphabetic phase) before more experienced readers are able to decode words via their letter-sound correspondences (full alphabetic phase). Share (1995) however, favours an item based explanation of acquisition of phonological recoding skills in which the route of word recognition (word reading) depends on word frequency and the amount of exposure the child has to a particular word. This perspective suggests that children may use either a visual or phonological decoding route across levels of reading development dependent on the word being read. Both Ehri's phase-based and Share's item-based theories propose that repeated decoding attempts of the same words or letter correspondences can allow the words to become accessed more quickly and automatically, that is, it becomes a word that can be read *by sight*.

Both phase based and item based theories of word reading highlight the contribution of phonological processing abilities such as phonological awareness that is required to mediate the phonological decoding process. The establishment of orthographic representations via a phonological route allow for direct access via the visual features on subsequent presentations of the word or using partial visual features with reference to phonological cues as in a modified dual-route model (Gillon, 2004). Comprehensive summaries of the dual-route models can be found in Gillon (2004) and Catts and Kamhi (2005).

The dual route theory of reading considers single words from a bottom-up perspective. While a bottom-up perspective is useful to consider the reading of single words, tasks that examine reading comprehension suggest that additional strategies such as analogy and prediction may be used in word reading. That is, word reading within context can use bottom-up or top-down strategies or a combination of these. Therefore it is also important to briefly consider how word reading within text might occur.

2.2.1. Top-Down, Bottom-Up and Interactive Written Word Processing

Words in text may be read via top-down or bottom-up processes or more likely an integration of the both (Gillon, 2004). If a person has some prior understanding of the text, he/she is reading they may engage a processing approach that is *top-down* using the words semantic context and the reader's knowledge of the world (Stackhouse & Wells, 1997). That is, they use their prior knowledge such as knowledge about context, sentence structure and semantic relations to make informed guesses to read (Gillon, 2004). If a person is not aided by the context he/she needs to engage in *bottom-up* processing, that is, either by recognising the visual features of the word (sight word reading), or decoding the word by converting letters to phonemes which are then blended back together to realise a phonological sequence (Catts & Kamhi, 2005; Stackhouse & Wells, 1997). Once the letters have been converted to phonemes the phonological sequence is thought to be in the same form as a spoken word and follows the same processing path.

These two polar aspects of processing the written word (top-down and bottom-up) have led to differences in the teaching of reading. Current literature suggests that for good readers an interaction of these two processes occurs - the interactive theories. When the contextual support is poor, or the word unfamiliar then the person must depend more on decoding skills and adopt a bottom-up approach. However, when the word or the topic is highly familiar many of the words may be predicted and therefore processed in larger chunks in accordance with a top-down process. A skilled reader can employ an interaction of these processes simultaneously and automatically as required with relatively little conscious effort (Frith, 1999; Gillon, 2004). For example, a word may be partially decoded (a bottom-up process) while a top-down approach such as analogy is employed to realise the word (Stackhouse & Wells, 1997).

Each of the two potential polar processes will have various demands on supporting cognitive skills. For example, to utilise a top-down approach strong language skills would be beneficial as well as more general world knowledge to assist in predicting the meaning of the words. To utilise a bottom-up strategy an understanding of the letter –sound relationships and the ability to manipulate these in sound blending is required or well-established orthographic representations to read known words. Different skills may be relevant at different stages of reading development (see Paul, 2001). There is an argument that beginner or unskilled readers who have not developed adequate decoding skills may rely more on top-down processes using context and their prior knowledge to read (King & Quigley, 1985). However Share (1995, p.154) points out that because the unfamiliar words that are most likely to be guessed are the hardest to predict, "contextual guessing is least helpful when it is needed most".

The strategies for word reading employed by children with a significant hearing loss may be different to those used by children with normal hearing. The next section considers how the different approaches to written word processing could apply to children with a significant hearing loss.

2.2.2. Written Word Processing: Implications for Children with a Hearing Loss

Children with a significant hearing loss are a unique population in terms of the literature suggesting that phonological knowledge is needed for reading. Children with a hearing loss can be considered at risk for difficulties with the processing of phonological information and therefore may have difficulties with *bottom-up* reading skills, particularly of unfamiliar words that would require phonological decoding. It is possible these children become more reliant on top-down versus bottom-up strategies or that they are more dependent on using a word-specific orthographic route to word reading.

There is some evidence that children with a significant hearing loss who are good readers use both top-down and bottom-up processes more effectively than children with significant hearing loss who are poorer readers. Kelly (1995) investigated whether skill in using top-down and bottom-up processing was different for nine skilled[7] readers and nine average readers with a severe-profound hearing loss. A word-by-word moving window task was used to record reading times of the skilled and average readers for both familiar and unfamiliar text, and interrupted and uninterrupted text. They found

[7] Students were grouped as skilled or average on their performance on a reading comprehension task that had been standardised on children with hearing impairment.

that both skilled and average readers read familiar text faster than unfamiliar, that is, both utilized top-down processing strategies. While there was no significant difference between the groups in the manner in which they used top-down processing (both groups were aided by prior text and topic familiarity) the skilled readers were significantly faster and more fluent readers in all conditions. It was suggested that the effectiveness of employing bottom-up processing discriminated the skilled versus average readers. This evidence suggests that children with a significant hearing loss who are skilled readers, similar to children with normal hearing, are better at reading tasks that require bottom-up processing than less skilled readers.

Children with a significant hearing loss, at least those children using sign language, can exhibit visual word recognition[8] skills as efficient as that of children with normal hearing and do not use a phonological strategy in doing so (Miller, 2006). However, in tasks when a phonological route must be employed such as in reading nonwords or novel words they must use a phonological strategy. Studies that have included tasks that require the use of a phonological strategy to read, such as nonword reading tasks, provide evidence that children with a significant hearing loss can employ a phonological strategy to word reading when required (see Perfetti & Sandak, 2000). There is also some evidence that adults, who have a significant hearing loss, activate different areas of the brain compared with hearing adults on both tasks that do not necessitate a phonological route such as visual lexical decision and tasks that are more dependent on a phonological route such as rhyme decision tasks judgement tasks (Aparicio et al., 2007). Interestingly, such findings suggest that rather than relying less

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[8] Visual word recognition tasks involve deciding whether two written words are the same or different.

on a phonological route, adults with a significant hearing loss may be more dependent on using a phonological route.

In children with normal hearing phonological processing abilities have been related to performance on bottom-up processing tasks such as list word reading. Phonological processing is a complex phenomenon that may have a direct and indirect impact on an individual's ability to read. Understanding the underlying phonological processing abilities of children with a significant hearing loss may explain the significant reading, speech and language difficulties that these children have typically experienced and may explain the variability in performance between children. The next section explores the intriguing phenomenon of phonological processing in relation to reading.

2.3. Phonological Processing and Reading

Phonological processing encompasses an array of abilities from encoding and storing incoming information in working memory and the lexicon, accessing a stored phonological representation, and retrieving representations from the lexicon. These processes also draw on and interact with other abilities, including speech and language skills. The following sections summarise selected literature about the different areas of phonological processing and the relationship of these aspects of phonological processing with reading, speech and language in children with normal hearing. This review provides important background for exploring the phonological processing abilities of children with a significant hearing loss.

2.3.1. Phonological Working Memory

Working memory is believed to be responsible for the temporary storage of various types of information (e.g. visual, spatial, verbal), for approximately 1 to 2 seconds, during cognitive tasks (Hulme & Roodenrys, 1995; King & Quigley, 1985). Working memory is a temporary store and it is believed that information quickly begins to decay, leaving progressively less distinct representations (Hulme & Roodenrys, 1995).

A model of working memory that has been widely referred to in the literature (e.g., Briscoe, Bishop, & Frazier Norbury, 2001; Gathercole, Pickering, Ambridge, & Wearing, 2004; Leonard, Weismer, Miller, Francis, Tomblin, & Kail, 2007; Montgomery, 2002; Weismer et al., 2000) is the three-component[9] model of working memory proposed by Baddeley and Hitch in 1974 (see Gathercole & Baddeley, 1993). In this model three components of working memory are identified, the *central executive* (responsible for the coordination of activities, regulatory activities and the transmission of information rather than storage), the *visuospatial sketch pad* (responsible for short-term processing of information with a visual or spatial component), and the *phonological loop* (temporary store of verbal and acoustic information) (Baddeley, 2000, p.418). The visuospatial sketch pad and phonological loop are thought to be specific domains and are referred to as *slave systems* (Baddeley, 2000; Gathercole et al., 2004). The capacity of these three distinct components of working memory have been found to undergo linear increases from 4 to 15 years of age (Gathercole et al., 2004).

[9] More recently Baddeley (2000) extended the original three-component model to include an additional component, the episodic buffer. The episodic buffer is defined by Baddeley (2000) as an interface between the slave systems and long-term memory. The inclusion of this additional component to working memory helps to explain the facilitatory effect of context on immediate recall as well as the integration of sensory information (Baddeley, 2000).

Phonological codes have been found to be the most efficient means of storing verbal information (see Catts, 1989; Catts & Kamhi, 2005), at least for children with normal hearing. The phonological loop is the component of working memory believed to temporarily store phonological information in working memory (Baddeley, 2000; Gathercole et al., 2004; Jones, Macken, & Nicholls, 2004; Montgomery, 2002). Various terms such as verbal short-term memory (Baddeley et al., 1998; Griffiths & Snowling, 2001; Vance & Mitchell, 2006), verbal working memory (Montgomery, 2002), and short-term phonological memory (Baddeley et al., 1998) have been used generally to refer to the temporary retention of verbal information as well as in reference to the phonological loop. In this thesis the term phonological working memory refers specifically to the phonological loop component of working memory.

The phonological working memory is thought to have storage and rehearsal components (Baddeley, 2000; Gathercole et al., 2004). Subvocal rehearsal is thought to assist in maintaining information in phonological working memory (Baddeley, 2000; Baddeley et al., 1998; Gathercole & Baddeley, 1993; Wagner, Torgesen, & Rashotte, 1999) and in recoding visual information into a phonological form (Gathercole et al., 2004), in such processes as phonological decoding. The subvocal rehearsal component can be conceptualized as the process by which individuals repeat verbal information (silently or aloud) to keep it current in memory and is thought to develop later than the storage components (Baddeley et al., 1998).

A secondary process, redintegration, is said to be employed during the decay of phonological information in the phonological working memory to restore this information (Gillam, 2002). Redintegration is not part of phonological working memory, but rather draws on phonological representations in long-term memory, using the partially retained information from the process of decay, to check against existing vocabulary and to trigger recall of the item (Gathercole et al., 1997; Gillam, 2002).

Researchers have used various tasks in an attempt to gain a measure of an individual's phonological working memory capacity. Given that spoken language is primarily processed sequentially (as opposed to spatially), sequential memory tasks such as digit recall have typically been used to contribute to a measure phonological working memory. A common method of measuring recall performance is using memory span tasks (Hulme & Roodenrys, 1995), and with digits, this is the longest series of digits that a person can immediately recall. Forward digit recall tasks have commonly been used as a measure of the phonological working memory (e.g., Adams & Gathercole, 1995; Gathercole et al., 1997; Gathercole et al., 2004; Wagner et al., 1993). Backward digit recall tasks have also been used as measures of phonological working memory, however such tasks are said to measure phonological working memory as well as other working memory components such as the central executive which is responsible for the coordination of activities, regulatory activities and the transmission of information rather than storage (Gathercole et al., 2004).

Multisyllabic nonword repetition tasks are also said to be a useful measure phonological working memory (Baddeley et al., 1998; Gathercole et al., 1997; Gathercole et al., 2004), and have frequently been used as a measure of phonological working memory in children with normal hearing (e.g., Adams & Gathercole, 1995; Fowler & Swainson, 2004; Gathercole et al., 1997; Leonard et al., 2007; Montgomery & Windsor, 2007; Passenger et al., 2000). In repeating a novel or nonword, one has no prior lexical representation to assist with access to pre-existing and practiced articulatory patterns for accurate pronunciation. Therefore, nonword repetition is based on the ability of the person to accurately derive and temporarily store the phonological code (nonword) (Leitao et al., 1997). Nonword repetition tasks may provide a more accurate assessment of phonological working memory than other tests such as digit span (Baddeley et al., 1998; Catts & Kamhi, 2005; Gathercole et al., 1997) because digit span may benefit from lexical support for retention such as in redintegration. However more recently it has been suggested that lexical representations may also assist nonword repetition (Thomson, Richardson, & Goswami, 2005) particularly when nonword tests include words with lexical or morphological components (e.g., 'ing') (Archibald & Gathercole, 2006). Further there is some debate about whether nonword repetition reflects other speech processing abilities (see Vance & Mitchell, 2006).

Phonological working memory has a role at a number of stages in spoken and written language processing. For example, phonological working memory is thought to play an important part in the grapheme-phoneme conversion process (Jones et al., 2004) and holding phonological representations, particularly of long words, temporarily during vocabulary acquisition (Baddeley et al., 1998; Montgomery, 2002). Longer words need greater specification and have more information to retain. Baddeley et al. (1998 p.161) suggested that the "effective capacity of the phonological loop is diminished when list items have long names".

Evidence of a relationship between children's existing vocabulary and word learning ability has been interpreted as indicating that if a new word contains a familiar phonological form, existing vocabulary can support word learning (Baddeley et al., 1998). However, in the early years of word learning, limitations in phonological working memory (either in the encoding or retention of phonological representations) may slow word learning and numerous repetitions of words may be required to establish adequate lexical storage. Information can only be temporarily held in the working memory before it is transferred to long-term memory or it is lost (Vance & Mitchell, 2006). In particular the phonological representations of polysyllabic words are likely to be harder to retain and may not be held in a well-specified form long enough for the long-term representations to be established. If phonological representations are only poorly maintained within the working memory it does not necessarily mean that the resulting representations in the lexicon need also be poorly specified once they are learned. It does however imply that a greater number of repetitions of the word or exposure to a word will be required for adequate specification of the phonological representation in the long-term store, the lexicon.

The specification of phonological representations in working memory may be affected by perceptual and/or encoding difficulties. Gathercole (2006) suggests that phonological working memory 'storage' is affected by both the encoding of representations and the endurance of these representations. Vance & Mitchell (2006) conceptualise the capacity of phonological working memory to store phonological representations as limited, but affected by the encoding process. These authors state that "if the processing of material is relatively *easy* more resource is available for storage than if the processing is more *difficult*" (p.146). The notion of both encoding and endurance of phonological representations contributing to an individual's performance on tasks requiring temporary storage of phonological information has implications for children who might experience perceptual difficulties such as children with a significant hearing loss. If encoding of speech information is relatively difficult for these children due to perceptual difficulties, then they may have less resources to devote to the endurance of the representations, the end result being potentially poorer performance on phonological working memory tasks. In addition, if children with a significant hearing loss require more repetitions of words to establish long-term representations, then word learning is likely to be slower resulting in a reduced vocabulary.

2.3.1.1. *Phonological Working Memory and Word Reading*

The influence of phonological working memory on word reading outcomes of children with normal hearing has not been fully established. Performance on phonological working memory tasks has been associated with reading (Brady et al., 1983; Muter & Snowling, 1998; Passenger et al., 2000), however it is possible that this relationship is mediated by other abilities that phonological working memory more directly influence. For example, Wagner et al. (1997) investigated the influence of measures of phonological processing (phonological awareness, phonological working memory and phonological retrieval) and vocabulary on the word reading performance of 216 children with normal hearing over time: yearly from kindergarten to Grade 4. Latent variables of phonological working memory and word reading were used in structural equation model analyses. Tasks of sentence repetition and digit span were used to comprise phonological working memory, and the Word Identification and Word Analysis subtests from the Woodcock Reading Mastery Test were used to comprise the word reading variable. Wagner et al found that individual differences in phonological working memory did not independently influence subsequent individual differences in word reading for either beginning or skilled readers. However, in another study investigating predictors of reading accuracy in children with normal hearing, Muter and Snowling (1998, p.332) reported that "nonword repetition scores obtained at ages 5 and 6 proved strong long-term predictors of reading accuracy at age 9".

It has been suggested that phonological working memory has a role in the mediation of new word learning (Baddeley et al., 1998; Gathercole, 2006; Gathercole et al., 1997; Montgomery, 2002). Performance on nonword repetition tasks has been significantly related to vocabulary acquisition (Gathercole, 2006; Gathercole et al.,

1997) and therefore it is possible that links between phonological working memory and reading are mediated by related skills such as vocabulary size. However, there is also some evidence that poor readers with normal hearing perform more poorly than good readers on phonological working memory tasks and speech perception tasks when presented in background noise (Brady et al., 1983; Mody et al., 1997). Such results can be interpreted as children with reading difficulties having difficulties with the encoding and subsequent endurance of phonological information in working memory.

2.3.2. Phonological Awareness

In broad terms, phonological awareness is an explicit awareness of the internal phonological structure of words and the ability to manipulate the phonological structure (e.g., Catts & Kamhi, 2005; Gillon, 2004; Passenger et al., 2000; Stackhouse, Wells, Phil, Pascoe, & Rees, 2002; Wagner et al., 1999; Wagner et al., 1997). In this thesis phonological awareness refers to the broader task of reflecting on phonological information at any level (syllable through to phonemic) and phonemic awareness is used specifically with reference to an awareness of individual phonemes.

Phonological awareness is developmental and children change in the level at which they can reflect and operate on language (Carroll, Snowling, Hulme, & Stevenson, 2003; Metsala, 1999; Stackhouse et al., 2002). In the initial stage of phonological awareness children show awareness of word length units within compound words; this is followed by recognition of syllables within words (syllabic awareness), and then onset/rime (intrasyllabic awareness). The final stage is phonemic awareness. A phoneme is the smallest contrastive unit in the sound system of a language. This means that if a phoneme is changed, the meaning of the word is changed. Phonemic awareness is the ability to access and manipulate the phonemes within words, for example, the ability to segment the word 'dog' into three phonemes.

Although phonological awareness is a metalinguistic skill, performance on phonological awareness tasks are thought to provide information about the specificity of a child's underlying phonological representations. It is the underlying phonological representations that are reflected upon in phonological awareness tasks. Performance on phonological awareness tasks is thought to reflect the level of specification of the underlying phonological representations (Elbro et al., 1998; Rvachew & Grawburg, 2006; Sutherland & Gillon, 2005; Thomson et al., 2005). The level of specification of the phonological representations will directly affect the extent to which phonological awareness tasks can be performed. If a child is able to reflect on and manipulate the individual sounds of a word, presumably the phonological representation of this word within the lexicon must be sufficiently well specified to enable this to occur. For example if the child is able to segment the word 'spoon' into [s p u n] the phonological representation must well specified at a phonemic level.

2.3.2.1. Phonological Awareness and Word Reading

In children with normal hearing phonological awareness is an area that has received a lot of attention with respect to its relationship with reading outcomes (e.g., Bryant, MacLean, Bradley, & Crossland, 1990; Catts & Kamhi, 2005; Ehri et al., 2001; Foy & Mann, 2001; Gillon, 2004; Metsala, 1999; Muter et al., 2004; Stahl & Murray, 1994; Wagner et al., 1997), in particular word level reading (nonword and sight word) (Metsala, 1999), and more recently speech production (Bird et al., 1995; Gillon, 2005; Leitao et al., 1997; Rvachew & Grawburg, 2006). Reading via a phonological route requires phonological awareness. Whether by analogy with rhyming words or in one-to-one grapheme– phoneme conversion, a child needs to be able convert graphemes into phonemes, hold them in working memory and then blend them back together to access a phonological representation of a word. It has been suggested that performance on tasks of phonological awareness have a direct relationship with reading development. For example, Wagner et al. (1999, p.46) state "Children with well-developed phonological awareness learn to read more easily than do children with poorly developed phonological awareness".

Phonological awareness is a strong predictor of future reading ability for young pre-readers (e.g., Bryant et al., 1990; Hogan, Catts, & Little, 2005; Muter et al., 2004; Wagner et al., 1997). Further this relationship appears to persist over time; at least during the years of learning to read (Muter et al., 2004; Wagner et al., 1997). For example, Muter et al. (2004) measured the phonological awareness abilities and word reading outcomes of 90 children in the United Kingdom over time, obtaining the first measurement on school entry (average age 4;9 years) and therefore prior to reading instruction. They found that phonemic awareness prior to reading instruction was a significant predictor of word reading approximately 1 year later.

Wagner et al. (1997) (see section 2.1.1.6) conducted an in-depth 5-year longitudinal study to investigate the contribution of phonological processing skills to word reading over time. There were five phonological awareness tasks used to construct the latent variable of phonological awareness, all of which were presented without picture stimuli. These included, phoneme elision, sound categorization, phoneme segmentation, blending phonemes into words and blending phonemes into nonwords. Wagner et al reported that phonological awareness influenced individual differences in word reading across time (Years K – 4).

Further evidence to support the role of phonological awareness in reading comes from outcome studies showing improvements in the reading ability of young children after completing intervention programs that promote explicit awareness of the sound structure of words (e.g., Ball & Blachman, 1991; Cunningham, 1990; Ehri et al., 2001; Gillon, 2005; Torgesen, Wagner, Rashotte, Rose, Lindamood, Conway, & Garvan, 1999b). For example, a meta-analysis conducted by the National Reading Panel in the United States of America, found that training programs in phonological awareness that explicitly highlighted the phonemic components of words and incorporated letters were most effective in promoting reading development (Ehri et al., 2001). Thus good phonological awareness seems to be important for achieving good reading outcomes.

2.3.3. PHONOLOGICAL RETRIEVAL

Phonological retrieval is the name given to the process by which phonological codes (pronunciation of a word or word segment) are retrieved from long-term memory (Allor, 2002; Wagner et al., 1993). Retrieval of phonological codes is necessary to speak aloud the name of a picture. Rapid automatised naming tasks have commonly been used as a measure of phonological retrieval ability (e.g., Foy & Mann, 2001; Griffiths & Snowling, 2001; Leitao et al., 1997; Wagner et al., 1993; Wagner et al., 1997). Rapid automatised naming tasks typically use serial presentation of stimuli such as numbers, colours, common objects or letters, presumed to be very familiar (overlearned or automated). If the stimuli are well practiced they should have precise and adequate representation in memory and therefore purely the speed and accuracy of retrieval from long-term storage (lexicon) is assessed rather than the lexicon. Findings of performance on rapid automatized naming tasks correlating with word reading outcomes, but not vocabulary support the notion that these tasks measure the retrieval process rather than the lexicon (Griffiths & Snowling, 2001).

2.3.3.1. Phonological Retrieval and Word Reading

Rapid retrieval of phonological codes from the lexicon has frequently been associated with reading skills in children with normal hearing (e.g., Catts, Fey, Zhang, & Tomblin, 2001; Cronin & Carver, 1998; Griffiths & Snowling, 2001; Manis, Doi, & Bhadha, 2000; Wolf, 1991), although the strength of this relationship has been found to reduce as children become more skilled readers (Wagner et al., 1997). It has been suggested that both rapid automatized naming and phonological awareness are perhaps the most important predictors of reading ability in children, and that those who have difficulties with both rapid automatized naming and phonological awareness tasks have greater difficulty in learning to read than those with a single difficulty (Bowers & Wolf, 1993; Wolf & Bowers, 2000). Wagner et al. (1997, p.469) point out that "efficiency with which children retrieve phonological codes associated with letters, word segments, and whole words should influence the success with which they can use phonological information in decoding." This suggests that to be an efficient reader one must be able to quickly and accurately retrieve a phonological code from the visual information (i.e., printed word).

However the source of commonality between performance on rapid automatized naming and reading tasks is unclear. It is unclear whether phonological awareness and rapid automatized naming account for the same variance in predicting word reading outcomes, as both draw on the phonological representations, or whether they contribute differentially. Catts, Fey, Zhang and Tomblin (1999) investigated the contribution of phonological processing and oral language to the reading skills of 604 children grouped as either good or poor readers. Catts et al found that although 29.1 % of poor readers (1 SD below the mean) had deficits in both phonological awareness and rapid automatized naming, 25.5% had a deficit in phonological awareness, but not rapid automatized naming and 15.5% had a deficit in rapid automatized naming, but not phonological awareness perhaps suggesting differential contribution for some children and a common underlying factor influencing all the skills for others. Wolf and Bowers (2000, p.322) suggest that the difficulties with rapid automatized naming tasks that some children with reading difficulties have may be "independent of phonology and thus not subsumable under it", leading them to propose that other processes such as timing mechanisms may be responsible for the relationship between reading and rapid automatized naming rather than just phonological processes (Wolf, Bowers, & Biddle, 2000). Wolf and Bowers (1993; 2000) coined the term *Double-Deficit Hypothesis*, proposing that core phonological deficits and core naming speed deficits in reading dysfunction are independent (an overview is provided by Wolf & Bowers, 2000).

A relationship between performance on picture naming tasks used to determine speech production skills and reading ability in children with normal hearing has also been well documented (e.g., Larrivee & Catts, 1999; Nathan, Stackhouse, Goulandris, & Snowling, 2004; Stackhouse & Wells, 1997; Swan & Goswami, 1997b). In addition to articulation ability, performance on picture naming tasks may be affected by the quality of phonological representations and phonological retrieval abilities (refer to section 2.1.1). The strongest links between reading and speech production difficulties have been for children with expressive phonological difficulties rather than articulation difficulties and co-occur with difficulties in other areas of phonological processing (Bird et al., 1995; Larrivee & Catts, 1999; Leitao et al., 1997; Nathan et al., 2004). Studies that show difficulties in speech production and reading and/or phonological processing have been interpreted as implicating an underlying phonological representations deficit (Bird et al., 1995; Larrivee & Catts, 1999; Swan & Goswami, 1997b).

2.3.4. Summary

Reading, speech and language difficulties in children with normal hearing have been associated with difficulties in their underlying phonological processing abilities. The specific aspect of phonological processing that is responsible has not been found to be consistent across groups or tasks and it remains unclear whether problems identified include core deficits in phonological awareness, phonological working memory, and/or phonological retrieval or whether there is a core deficit in the underlying phonological representations.

Although a number of studies have explored the relationship of underlying phonological processing abilities to the development of key performance areas of reading, speech and language in children with normal hearing, there are few studies that explore these relationships in children with a hearing loss. Children with a significant hearing loss can be considered at risk for having poor phonological processing abilities. If they have poor access to the speech signal, perceptual analysis (phonetic detection and discrimination) and initial phonological encoding in working memory during word learning is likely to be less precise, and/or subject to rapid decay, particularly for long words, and therefore lead to difficulty establishing well-specified phonological representations in the lexicon as well as difficulties in skills that utilize these phonological representations such as phonological awareness, and phonological retrieval (particularly production of polysyllabic words).

The cochlear implant has provided many children with a significant hearing loss with greater access to the speech signal than they would have without it. Although, the speech perception results of children using a cochlear implant (reviewed in chapter 1) suggest that the cochlear implant does not provide complete access to the speech signal, many children using a cochlear implant are reliant on spoken language to communicate.

The reliance on spoken language implies that to some degree they engage in processing phonological information, that is, encoding, storing and retrieving phonological information.

It is well-established that children with a significant hearing loss experience difficulties in the area of reading (e.g., Dyer, Szczerbinski, MacSweeney, Green, & Campbell, 2003; LaSasso & Mobley, 1997; Paul, 1999; Traxler, 2000; Wauters, Van Bon, & Tellings, 2006). However, there is large variability in the reading outcomes of children with a significant hearing loss, particularly in children who use assistive listening devices, including hearing aids and cochlear implants, that enable auditory access to spoken language. There are very few studies that have specifically looked at phonological processing abilities and reading outcomes in children with a significant hearing loss. Overall the status of the phonological processing abilities of this population has not yet been clearly established, nor is it clear whether phonological processing abilities are specifically related to reading outcomes in children with significant hearing loss (e.g., Izzo, 2002 versus Dillon & Pisoni, 2006). Understanding the underlying phonological processing abilities of children using a cochlear implant may explain the significant reading, speech and language difficulties as well as variability in these skills, which as reported in chapter 1, is typical of children using a cochlear implant.

2.4. Relationships Between Reading, Language, Speech Production and Phonological Processing in Children With a Hearing Loss

The review of studies in normal hearing children highlighted complexities in the area of phonological processing and showed that multiple variables need to be considered within the same cohort of children if factors influencing reading outcomes are to be understood. By comparison, in the field of cochlear implantation, relatively little is known about the relationships between reading outcomes and language, speech production and phonological processing for children who use a cochlear implant. Given that there has been some research exploring these later two relationships for children with a hearing loss who do not use a cochlear implant, the findings from this research are considered first, to provide a context for understanding results to date for children who do use a cochlear implant.

2.4.1. Phonological Processing in Children with Hearing Loss Not Using a Cochlear Implant

2.4.1.1. Phonological Awareness and Hearing Loss

Children with a hearing loss without a cochlear implant have been reported to have significantly poorer phonological awareness abilities than children with normal hearing (e.g., Colin, 2007; Dyer et al., 2003; Harris & Beech, 1998; Kyle & Harris, 2006; Miller, 1997; Sterne & Goswami, 2000). However it is not clear whether phonological awareness ability is related to reading outcomes in children with a hearing loss. Some studies have found that a relationship exists between phonological awareness and reading outcomes of children with a significant hearing loss (Colin et al., 2007; Dyer et al., 2003; Harris & Beech, 1998; Corcoran Nielsen & Luetke-Stahlman, 2002) while others have found no such relationship (Izzo, 2002; Kyle & Harris, 2006; Miller, 1997). Some of the difference between the findings of the studies may be accounted for by differences in participant characteristics, in particular age and type of communication mode, and assessment tasks. Typically assessment of phonological awareness in children with a significant hearing loss has involved picture tasks that do not require a spoken response rather than orally presented tasks that have typically been used in the assessment of phonological awareness in children with normal hearing.

Sterne and Goswami (2000) conducted three experiments to compare the phonological awareness skills of children with a profound hearing loss at the level of syllable, rime and phoneme to those of children with normal hearing. In the first experiment there were 15 children with a significant hearing loss aged 9;9 years to 13;3 years who attended either a school that used OC or a school that used TC. The group with a hearing loss were compared with two groups with normal hearing: a chronological age-matched group and a reading age-matched group. To determine the syllable awareness skills of the participants, pairs of pictures were shown which were either congruent (same in orthographic and phonological length) or incongruent (different in orthographic and phonological length). The participants were required to give a yes/no answer to each pair as to whether they were the same length. Sterne and Goswami found that the children with a significant hearing loss had syllable awareness skills commensurate with their peers with normal hearing. Given that syllable awareness is a pre-reading skill and the participants were over 9 years of age, it is possible that the lack of difference between groups was due to ceiling effects.

In the second experiment the rhyme awareness skills of 14 children (average age 10;4 years) with a significant hearing loss educated in either an OC or TC setting were compared with the rhyme awareness skills of a reading-age matched group of children with normal hearing. A picture task was given in which the participants had to chose the picture that rhymed with a target picture from a choice of two. Sterne and Goswami reported that the children with normal hearing, although younger than the children with a hearing loss, had significantly better rhyme awareness skills. Analysis of the responses revealed that where possible the children with a hearing loss used orthographic cues to make rhyme judgements. In the third experiment the phonological decoding skills of the children with a hearing loss and reading-matched control from experiment one were measured. To measure phonological decoding the children were given a picture and four written words and asked which word sounded like the picture. The children with a hearing loss performed significantly worse than the control group who performed at ceiling.

The children in the Sterne and Goswami (2000) study were older than participants in studies that have investigated phonological awareness in children with normal hearing. In another study that used 24 younger children (5 years old at initial data collection), Harris and Beech (1998) compared the phonological awareness abilities with reading skills of 24 beginner readers with a severe or profound hearing loss to 56 children with normal hearing over 2 years. The group with a hearing loss used a variety of communication approaches including TC and OC. The phonological awareness measure consisted of a series of three line drawings and children had to identify which picture did not have the same initial, middle or final sound. The reading measure was a single word reading comprehension task in which the participants where shown a picture and had to choose the corresponding word from five written words. Other tasks designed to measure fingerspelling, signing and articulation ability and language comprehension were also administered. Harris and Beech found that the children with a significant hearing loss had significantly poorer phonological awareness and reading ability than the children with normal hearing, however phonological awareness was significantly correlated to reading gain for both participant groups. Language comprehension was also significantly correlated to reading gain after 1 year, but not at the 2nd year of testing. The results of the Harris and Beech study suggest that children with a significant hearing loss with better phonological awareness skills tend to have better reading skills, although this is not always the case. Analysis of individual participant profiles showed that the child with the second highest reading score who used sign to communicate had very poor phonological awareness ability. A likely explanation for such a finding is that the participant was very effective in using an orthographic-visual approach to reading, as the reading task was not dependent on a phonological strategy being used.

It is likely that children using oral communication have different phonological awareness skills to children using sign to communicate. This issue was looked at by Miller (1997). Miller investigated the phonological awareness and reading skills of 16 children using OC and 15 signing children in fourth to ninth grade with a pre-lingual severe to profound hearing loss. In addition, a control group of 36 children with normal hearing in fourth to ninth grade were included. A phonological awareness task was administered that required the participants to identify two pictures from a choice of four that either had the same initial phoneme, final phoneme or rhymed. Although reading was not specifically measured in this study, each participant's teacher was asked to provide an estimate of the child's reading level. The study was conducted in Hebrew. In Hebrew there are two graphemes for some phonemes. This enabled information to be gained about the strategy used by the participants. Two groups of stimulus items were constructed; the first group of stimuli used words that could be judged as same sounds or rhyming using only a phonological processing strategy, while the second group could be related using either a phonological or graphemic strategy. The results indicated that when a non-phonological process was sufficient to process the test items the OC participants were significantly less accurate than both the normal hearing and the signing groups and significantly slower than the normal hearing group. The accuracy of the children who used signing was not significantly different to the normal hearing group when a nonphonological process could be utilized. Interestingly the accuracy of the signing group was not significantly different to the OC group when a phonological strategy was obligatory. In addition accuracy on the phonological awareness task was not significantly related to the reading comprehension rating for either groups of children with hearing loss.

In a study investigating the phonological awareness, language and reading skills of 29 participants from ages 4;4 years to 13;5 years who used signed communication, Izzo (2002) found no relationship between reading outcomes and phonological awareness ability. Phonological awareness was measured using a similar task to that used by Miller (1997), in which the children had to choose two pictures from four that had the same initial, medial or final sound. A story retelling task was used to assess reading; the participants read a passage in English and then retold what they had read in their natural language, that is, sign. Number of grammatical structures used, as judged by two sign language raters reviewing an interview of the participants, was the language measure. The reading task could be completed using an orthographic strategy alone as long as the words were within the children's sight word vocabulary. Izzo reported that the phonological awareness scores of the participants were low, and only one participant scored over 50% correct. Izzo found no relationship between phonological awareness ability and reading retell, however the language measures was significantly correlated to reading retell. Izzo suggested the findings support an argument against the necessity of phonological awareness for reading development. However, the majority of the participants reading scores were below their grade level.

Overall, the studies reviewed in this section indicate that children with a significant hearing loss not using a cochlear implant do not have phonological awareness abilities commensurate with children with normal hearing. One interpretation of poorer phonological awareness abilities in children with a significant hearing loss is that their phonological representations, which provide the platform for phonological awareness, are underspecified in this population (Colin et al., 2007). In addition, contrary to what has been documented for children with normal hearing, some of the studies indicate that phonological awareness abilities are not related to reading outcomes in children with a hearing loss. However it is important to note that the measures of both phonological awareness and reading may account for this lack of relationship. The studies reviewed typically used comprehension level reading tasks rather than word level reading. In addition picture tasks were used to measure phonological awareness in which only a proportion of the items required the use of a phonological strategy for success. The phonological awareness skills of children using a cochlear implant may be different to those reported here, in addition there may be a stronger relationship between phonological awareness and *word reading* than with reading comprehension.

2.4.1.2. Phonological Working Memory and Hearing Loss

There is some evidence that when there is an option to use either a phonological or nonphonological strategy such as remembering pictures that can be named, children with a significant hearing loss will use a nonphonological strategy whereas a children with normal hearing typically encode this information phonologically in working memory (Harris & Moreno, 2004). However, there are instances where there is no option for visual encoding of information. Information such as remembering lists of spoken words or digits or repeating nonwords must be encoded in phonological working memory. There is limited evidence that children with only mild to moderate hearing loss have difficulties with the encoding process and in forming well-specified phonological representations in working memory and subsequently the lexicon (Briscoe et al., 2001; Gilbertson & Kamhi, 1995). For example, Gilbertson and Kamhi (1995) investigated the novel word learning skills of children with a hearing loss. They assessed 20 children with normal hearing and 20 children with mild-to-moderate hearing loss on tasks of nonword repetition, rapid automatized naming and novel word acquisition, recognition and retention. The children in the hearing loss group required significantly more repetitions of di- and polysyllabic novel words for acquisition and recognition. These findings suggest the children with a hearing loss experienced difficulty at some level of the encoding process and subsequently storage of phonological information. The group with a hearing loss also performed significantly poorer than the children with normal hearing on all tasks of nonword repetition (consonant-vowel-consonant, mono and polysyllabic words) indicating that encoding and maintaining phonological information in working memory is problematic for these children. However, once a word had been established in the lexicon of children with hearing loss, it seemed they had no difficulty with phonological retrieval as the children with hearing loss performed significantly better than the children with normal hearing on rapid automatized naming tasks (letters, numbers, colours and objects).

2.4.1.3. Phonological Retrieval and Hearing Loss

Investigations of the phonological retrieval abilities of children with a hearing loss using a rapid automatized naming task have rarely been reported in the literature. In addition to the study by Gilbertson and Kamhi (1995) reviewed above, Dyer et al. (2003) used a rapid automatized naming task in an investigation of the phonological processing and reading skills of 49 adolescents with a severe or profound hearing loss and using TC. Two control groups (one matched for chronological age and one matched for reading age) were included in the study. A cloze reading task, in which the participants with hearing loss were given four words to choose from for each sentence, was used to recruit children and in the correlation analyses. A rapid object naming task was used to assess rapid automatized naming. Other measures included in the study were speech and sign repetition rate, rhyme matching and nonword decoding. Dyer et al reported that the participants' performance on rapid automatized naming task was equivalent to a chronological age matched group and better than a reading age matched group with normal hearing. The performance of the children with a significant hearing loss on the rapid automatized naming task was not significantly related to the reading measure. These results combined with Gilbertson and Kamhi's (1995) results call into question the importance of phonological retrieval abilities to reading outcomes in children with a hearing loss.

2.4.2. <u>Phonological Processing in Children with Hearing Loss Using a Cochlear Implant</u>

The studies described in the previous sections used children with a hearing loss not using a cochlear implant. This section reviews the few studies that have investigated phonological processing in children using a cochlear implant. It begins with a detailed review of Geers (2003). A major project by Geers and her associates entitled '*Cochlear Implants and Education of the Deaf*' explored the relationships between reading and aspects of speech, language and phonological processing in children using a cochlear implant (Geers, 2003) [10]. Geers (2003) specifically identified predictors of reading performance in children who use a cochlear implant. It provided an initial view of possible factors related to reading in children using a cochlear implant from which future research could build. The investigation reported in this thesis builds on and extends the report by Geers (2003) and more recently a study by Fagan, Pisoni, Horn and Dillon (2007), which is the only study to date to examine possible factors that might be related to reading in children using a cochlear implant and oral communication. For this reason, an overview and critique of these two studies is presented, followed by a few other studies [11] that have examined specific relationships between reading and aspects of phonological processing for this group.

2.4.2.1. Review of "Predictors of reading skill development in children with early cochlear implantation" Geers (2003)

Geers (2003) examined variables contributing to reading outcomes in a group of 181, 8- and 9-year-old cochlear implant users; 83 of which were considered to use a TC mode and 98 an OC mode (cued speech, auditory-oral or auditory-verbal), in American educational settings. As part of this study and the larger research project, the

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[10] A summary of the reading results reported by Geers 2003 is provided in section 1.2.4.1. Section 2.4.2.1 focuses on the *relationships* of other variables with reading.

11 A number of the other studies reviewed have used the same or subgroups of the same larger participant group from the Geers larger research project and sometimes the same data.

participants' performance on tasks in the areas: speech perception, speech production, language, working memory, lexical decision, rhyme awareness and reading were assessed.

The lexical decision task required the participants to sort a set of cards containing written words into real words or nonwords. There were 62 irregular real words, 31 homophonic nonwords and 31 nonhomophonic nonwords. Geers (2003) reported that on average the participants sorted more of the nonwords as real words when they were homophonic to a real word, suggesting that in these instances the participants employed a phonological strategy to word reading.

On the rhyme decision task participants were asked to decide whether pairs of written words (with either similar or dissimilar orthography or phonology) rhymed. Geers (2003) reported on the pattern of responses given by the participants, finding that 72% of the rhyming decision errors were made when the words rhymed and had dissimilar orthography (e.g., word/bird). Such a finding suggests that many of the participants were using orthographic rather than phonological strategies for making rhyme judgements. A weak but significant correlation was found between the rhyme task and reading scores (r between 0.33 and 0.40 across reading tasks). As a non-standardised test was used to determine rhyme awareness in the Geers study it is unknown if the scores obtained by the participants were comparable to children with normal hearing and as only one aspect of phonological awareness was assessed the interpretation of this finding is limited.

Geers (2003) also examined the relationship of working memory to reading outcomes. Tasks of both forward and backward digit span from the Weschler Intelligence Scale for Children – 3rd Edition (WISC 111) (Wechsler, 1991) were administered. The group mean digit score for both forward and backward digit span (5.2

and 3.3 respectively) were below the normal range for children with normal hearing. Geers reported that both forward and backward digit spans were moderately associated with measures of reading (range = 0.43 to 0.54 across reading tasks). In children with normal hearing forward digit span tasks have been used as a component measure of phonological working memory whereas backward digit spans are used as a more general measure of working memory that taps into the central executive system. The presentation of digits in the Geers study was in the child's preferred communication mode (i.e., sign or speech). Therefore it is likely that for some participants in the Geers study the digit span task would also represent a construct of visual working memory.

In an attempt to remove some of the overlapping of variables and to determine variables predictive of reading in children using a cochlear implant, Geers (2003) then used a series of hierarchical multiple regression analyses using principal component scores as independent variables (Strube, 2003). Numerous specific variables were reduced to more general areas of communication (e.g., speech perception, reading and so forth). Strube (2003, p.15S) commented that "our major goal was to determine how the general categories of communication skill are influenced by the many predictor variables that were collected." The reduction of variables in a principal component analysis was done in an attempt to retain some statistical control over the large number of variables with relatively small participant numbers. Nonword reading, word reading and reading comprehension were all reduced to a single dependent variable, reading. A number of measures of language, speech perception and speech production were also converted to principal component scores. Geers found that all the processing and speech and language variables, with the exception of speech perception, added significant variance to the regression and therefore to predicting reading. The use of such a procedure was successful in providing some very general information about factors contributing to reading in children using a cochlear implant. However, the reduction of data removes detail and detracts from the specificity of the findings. For example, the correlation analysis showed a strong relationship between reading and speech intelligibility thereby suggestive of some commonality between the two areas. Geers suggests the source of this commonality may stem from underlying phonological skill that is common to both skills. However phonological processing abilities would presumably be better in children using OC as they are reliant on the processing of spoken language for communication whereas children using TC are more dependent on processing information visually for communication. Communication mode in the regression analysis was not predictive of reading outcome in this study. A reason for this may be the reduction of reading to a single variable. Reading comprehension draws more heavily on language than phonological processing abilities, and while word reading is a component of reading comprehension, in the multiple-choice reading task either or both top-down and bottom-up strategies to reading could be employed. It is conceivable that the reading comprehension of OC and TC users might be equivalent. However, the word attack task requires phonological decoding and is by the nature of the task dependent on speech production skills; the child has to correctly articulate a given nonword. Given that the speech production skills of the OC children were found to be significantly better than those of the TC children (Tobey et al., 2003), it could be predicted that the word wording (measured by word attack task) would also be better. A limitation of the reduction of variables to a single principal component score is that differences in the reading tasks lose their relevance. If the OC and TC children were compared across the reading tasks the results of the two groups may have been found to be quite different for the word attack task. These findings highlight the fact small changes in statistical analyses or differences in tasks administered may change the profile and relationships between outcomes. It is possible that the relationship between reading and other variables may be quite different for a single group of children who use oral communication, and further, might be quite different if the requirements of the reading task change.

The Geers (2003) study provides some initial information about some general areas that contribute to reading in a specific group of American children using a cochlear implant, who as a group use a variety of modes of communication. However, detailed analysis of the relationships between isolated aspects of reading and speech production, phonological processing and language in different populations of children using a cochlear implant continues to be lacking. To date it is largely unknown if different abilities contribute to word reading and reading comprehension. As discussed in earlier sections of this thesis, the skills involved in word reading are very different to those involved in reading comprehension. The Geers (2003) study did not answer the question of whether or how a range of phonological processing (phonological working memory, phonological awareness and phonological retrieval), and language abilities might influence word reading outcomes. Furthermore, Geers included participants from a variety of communication approaches and therefore could not answer the question of which variables are the best predictors of word reading and reading comprehension outcomes in children who only use oral communication.

There is a pressing need for an investigation into the relationships between reading comprehension and word reading, and a comprehensive range of factors such as speech (perception and production), language and phonological processing in children with a significant hearing loss that are as homogeneous as possible – this includes controlling for amplification device (e.g. cochlear implant), communication mode and educational setting. The one known study that has looked at aspects of phonological processing abilities in a single group of *oral* communicating children using a cochlear implant is reviewed below.

2.4.2.2. Review of "Neuropsychological correlates of vocabulary, reading, and working memory in deaf children with cochlear implants" by Fagan et al. (2007)

Fagan et al. (2007) investigated the possible relationships of reading outcomes with a number of variables including measures of phonological awareness, working memory, sensorimotor skills (hand position imitation, finger dexterity, imitation of rhythmic hand sequences and fine motor), visuomotor integration and receptive vocabulary, of 26 children in mainstream educational settings using a cochlear implant. The same tests of reading as used in the Geers (2003) and Dillon and Pisoni (2006) studies were administered (these studies included a cohort of the same participants). A composite score of the reading recognition and reading comprehension subsets from the Peabody Individual Achievement Test – Revised (Markwardt, 1998) was used as the reading measure, in addition to the word attack subtest of the Wookcock Reading Mastery Tests-Revised (Woodcock, 1998) as a nonword reading measure. Fagan et al also administered the Lindamood Auditory Conceptualisation Test – Third Edition (LAC3) (Lindamood & Lindamood, 2004) which measures 'perception of phoneme and syllable patterns' (Fagan et al., 2007, p.465) mediated visually using coloured blocks, and is standardised on children with normal hearing. This test was used as a measure of phonological awareness. Similar to Geers (2003) the digit span tasks (forward and backward) from the WISC 111 were administered as measures of working memory. Fagan et al found that the overall LAC3 group mean standard score was 88.2 and therefore within the normal range for children with normal hearing. However, forward and backward digit span mean group scores (6.5 and 5.0 respectively) were below the normal range for children with normal hearing, although these scores were higher than those reported by Geers (2003) in which both TC and OC participants were included. Fagan et al conducted a correlation analysis and reported a strong relationship between the composite reading measure, the nonword reading measure and the phonological awareness measure. Interestingly, Fagan et al found that scores on the backward digit span task, but not forward digit span task were significantly related to the phonological awareness and reading measures. Forward digit span has typically been used as a measure of phonological working memory, whereas backward digit span is thought to reflect a more complex task involving the central executive to coordinate information. Because tasks of phonological working memory (e.g. forward digit span) and phonological awareness and nonword reading are thought to involve the processing of phonological information it is surprising that there was no relationship between phonological working memory and phonological awareness. Also interesting was the significant relationship between the backward digit span task and phonological awareness and reading. Nineteen of the 26 participants were reported to have scored more than 1 standard deviation below the mean on the backward digit span task, whereas only 3 of the 26 participants scored more than 1 standard deviation below the mean on the measure of nonword reading. In spite of such large differences in performances on these tasks there was a significant positive correlation of r = .58 between these two measures. There were no scatter plots provided to ascertain whether the relationship between the variables was linear.

Fagan et al. (2007) also reported that not only was an overall reading measure (word reading and reading comprehension) strongly related to receptive vocabulary (r =

.76), but that a word reading task that used nonwords, was strongly related to receptive vocabulary (r = .70). The finding that nonword reading was also strongly related to receptive vocabulary with consideration to the research reviewed previously regarding phonological processing and word reading in children with normal hearing, prompts the question of whether there is a factor, such as specification of underlying phonological representations, that is common to both reading and vocabulary in oral communicating children using a cochlear implant. This issue is yet to be explored in the literature.

Phonological awareness tasks are also said to provide information about the underlying phonological representations. Fagan et al. (2007) used the LAC3 as a measure of phonological awareness. This assessment tool uses sequences of sounds rather than words and the publishers of the LAC3 report that it "measures an individual's ability to perceive and conceptualize speech sounds using a visual medium" (www.proedaust.com.au/psyc). It could be argued that the LAC3 taps into a different type of phonological awareness ability compared with the typical test battery used to measure phonological awareness (e.g., syllable or phoneme detection, deletion, segmentation and blending tasks). Specifically, the LAC3 requires the participant to represent number of sounds, similarity of sounds and sound changes using coloured blocks. It could also be said to be a measure of auditory analysis supplemented by a visual medium. It is impressive that the participants in the Fagan et al study as a group presented with auditory perceptual and analysis skills at the lower end of the normal range. However conclusions about the phonological awareness abilities of mainstream educated children using a cochlear implant cannot be drawn from a single study using a unique assessment tool with a small group of participants. Further, the methodological procedures for this study were not reported in detail. It was noted that data such as chronological age of one participant[12], and etiology of deafness for 17 participants were unknown. Fagan et al stated that the "relevant measures summarized for the purpose of this study, were administered as part of a larger study of the reading and phonological awareness in children with cochlear implants" (p.464). However the published reference provided by Fagan et al (i.e., Dillon & Pisoni, 2006), does not include any measures of phonological awareness and instead reports on nonword repetition. Because of the small number of participants and potential weaknesses in this study, further studies on the phonological working memory and phonological awareness abilities of oral communicating children using a cochlear implant are needed.

2.4.2.3. Phonological Awareness and Reading: Children Using a Cochlear Implant

Few studies have explored the phonological awareness abilities and reading outcomes of children using a cochlear implant (Fagan et al., 2007; Geers, 2003; Unthank, Rajput, & Goswami, 2000). There is also limited evidence on how the phonological awareness abilities of children using a cochlear implant compare to children with normal hearing. James et al. (2005) reported that children using a cochlear implant have poorer phonological awareness abilities than children with a severe hearing loss using hearing aids. James et al. (2005) examined the phonological awareness abilities of 18 school-aged children who used a cochlear implant and oral or sign-based communication at Time 1 and Time 2 (a year apart) to determine the

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[12] Although the authors state that standard scores were not obtainable for this participant and therefore scores were not included in the analysis, it is unclear whether this participant was included as one of the 26 participants.

development of phonological awareness in these children. As a standardised assessment was not used, they also measured the phonological awareness abilities of two hearing aid user comparison groups: those with a profound hearing loss and those with a severe hearing loss. Syllable, rhyme and phoneme awareness were measured using matching tasks (commonly referred to as detection level tasks); the child had to select a picture that had the same syllable number, rhyme or initial phoneme as the target picture. They reported that the children using a cochlear implant presented with similar hierarchal development of phonological awareness that has been documented in children with normal hearing; they had higher percentage correct scores on syllable detection tasks, second highest on rhyme detection and lowest on phoneme detection. Interestingly, they found that the children using a cochlear implant had poorer rhyme and phoneme awareness than the children with a severe hearing loss using hearing aids. As the assessment tasks used were not standardised it is unknown how the phonological awareness scores of the children compare to children with normal hearing. The average age of the children in the study was 8;4 years, therefore it could be predicted that the phonological awareness abilities of the participants were poorer than children with normal hearing who would be expected to easily match initial phonemes of words at an equivalent age. The James et al study provides initial information on an aspect of phonological awareness in some children using a cochlear implant. However in the James et al study there were only a small number of children who used oral communication and only 26% of the participants were in a mainstream educational placement.

Relatively little is known about the phonological awareness abilities of children using a cochlear implant. Phonological awareness abilities have been strongly related to reading skills in children with normal hearing. There is limited evidence that this may also be true for children using a cochlear implant. However more empirical evidence with a single group of cochlear implant users that use the same communication approach is needed to determine how such children's phonological awareness abilities compare to those of children with normal hearing, and how their abilities may be related to reading outcomes.

2.4.2.4. Phonological Working Memory: Children Using a Cochlear Implant

The few studies that have included a measure of phonological working memory have found that the phonological working memory of children who use a cochlear implant are significantly poorer than those of children with normal hearing (Fagan et al., 2007; Geers, 2003; Pisoni & Cleary, 2003; Pisoni, Cleary, Geers, & Tobey, 1999). The findings of this relatively small body of research suggest that those children who are best able to use the signal provided by the cochlear implant have a greater phonological working memory capacity. The findings provide support for Vance and Mitchell's theory (see section 2.3.1) that the capacity of the phonological working memory is affected by the ease of encoding phonological information. For example, Pisoni, Cleary, Geers and Tobey (1999) looked at the relationship of the working memory abilities of 43 children using a cochlear implant with their speech perception and speech intelligibility. The children in this study were part of the larger longitudinal research project led by Geers ("*Cochlear Implants and Education of the Deaf Child*" by Anne E. Geers and colleagues) and used a variety of communication approaches including TC and OC. The forward and backward digit span tasks from the WISC (Wechsler, 1991) were used as the measures of working memory. Pisoni et al reported that the participants' performance on speech perception tasks and a speech intelligibility task were related to their working memory. Pisoni et al further reported that cochlear implant users with the top 20% of scores on an open-set speech perception task (star performers) consistently performed better on a minimal pairs test (the participants were required to discriminate words based on one distinctive feature of manner, voicing or place) than a comparison group of poor performers on the open-set speech perception task. However, even the 'star' performers continued to have difficulty discriminating words only differing in place of articulation of one sound (e.g., pick/tick). This finding indicates that even cochlear implant users with the better outcomes have reduced auditory perceptual abilities for spoken language. Pisoni et al. (1999, pp.120 & 121) suggested that even the star performers are "encoding spoken words using 'coarse' phonetic representations that contain much less fine-grained acoustic-phonetic detail than is typically used by children with normal hearing". These children might therefore be expected to have less well-specified lexical phonological representations, although the children with better abilities encoding phonological information in working memory were not necessarily the same children with better vocabulary skills. When the participants in the Pisoni et al. (1999) study were tested in their preferred communication mode, there was no apparent difference in the receptive vocabulary skills between the star and poor performer groups. This finding prompts the question of whether phonological working memory plays as large a role in mediating vocabulary acquisition in children with a significant hearing loss as it is thought to in children with normal hearing. It is possible that children using a cochlear implant and a more visual mode of communication (e.g. TC) have a preference to encode information in working memory visually rather than phonologically (Harris & Moreno, 2004; King & Quigley, 1985).

There is some evidence that children using different modes of communication may differ in their preferred manner of encoding language. In a subsequent study, Pisoni and Cleary (2003) investigated the working memory abilities of 176 children using a cochlear implant. These children were part of the larger Geers (2003) project and used either OC or TC. The WISC (Wechsler, 1991) forward and digit span tasks were administered. Pisoni and Cleary found that children in OC environments that emphasised speech and listening had significantly better forward digit spans, but not backward digit spans than children in TC environments. Backward digit span tasks are said to be complex memory tasks that utilize the central executive as well as the phonological loop (Gathercole et al., 2004) and therefore the Pisoni and Cleary findings suggest that perhaps the central executive function of working memory is similar for children with different modes of communication, but that children using OC have significantly better developed phonological loop functioning (phonological working memory).

It has been argued in the literature of children with normal hearing that nonword repetition is a purer measure of the phonological loop in working memory than digit span tasks (Gathercole et al., 1997). Research investigating the nonword repetition abilities of children using a cochlear implant has recently been documented in a series of papers by Dillon and colleagues (Carter, Dillon, & Pisoni, 2002; Cleary et al., 2002; Dillon, Pisoni, Cleary, & Carter, 2004a; Dillon, Burkholder, Cleary, & Pisoni, 2004b; Dillon & Pisoni, 2006; Dillon, Pisoni, Cleary, & Carter, 2004c). All these studies were related and used the same or a subset of the same participants, but differed in the analysis of the results. For example, in the Dillon, Burkholder et al. (2004b) study, a group of normal hearing adults were asked to judge the accuracy of the participant's nonword repetitions on a scale of 1 –7 from failing to resemble the target word to a perfectly accurate production. Whereas Dillon, Pisoni et al. (2004a) conducted a detailed consonant and error analysis of the nonwords produced. The methods of analyzing and scoring the nonword repetitions in the above series of studies differed from the typically binary manner in which nonword repetition tasks have been scored in children with normal hearing. The most relevant of these related studies are reviewed here.

Dillon, Burkholder et al. (2004) reported on the accuracy of the repetition of nonwords by a subset of 76 participants from the Geers (2003) larger project using TC or OC. *Using the scoring method described above, they compared the nonword* repetition accuracy scores of the children in the OC group with the scores of children in the TC group. They found that the repetition of nonwords by children using OC was significantly more accurate than repetition of nonwords by children using TC. The nonword repetition task used in this study was not standardised. Therefore it is unknown how the nonword repetition abilities of these children compare with those of children with normal hearing. The researchers then conducted a regression analysis with nonword repetition accuracy ratings as the dependent variable. In opposition to the significant relationships between nonword repetition and digit span scores documented in children with normal hearing (Gathercole et al., 2004), Dillon et al reported that forward digit span scores did not significantly contribute to the variance in nonword repetition, but that measures of speaking rate, speech perception, speech production and exposure to oral communication were significant contributors. Speech perception difficulties would be likely to have more impact on the encoding of unfamiliar words (nonwords) than familiar words (digits), and speech production errors are likely to impact the scoring of nonwords rather than digits because nonwords were specifically measured via phonetic transcription. If the children in this study, who used either TC or OC had speech perception or speech production errors this may account for the lack of relationship between the two measures of phonological working memory. The independent variables of the regression analysis were strongly intercorrelated in this study (also refer to Pisoni and Cleary, 2003) and therefore the authors suggest the results should be interpreted with caution. It is possible that the lack of contribution of digit span scores to nonword repetition was due to limitations of a regression analysis with few participants and intercorrelations between independent variables.

In a subsequent study using the same participants and nonword repetition accuracy data, Dillon and Pisoni (2006) investigated the relationship between nonword repetition accuracy scores and reading (as measured in the Geers (2003) larger study). Dillon and Pisoni reported a significant relationship between nonword repetition accuracy ratings and reading measures. However, Dillon and Pisoni found that once lexical diversity was partialled out of the correlations, nonword repetition accuracy ratings were not significantly correlated with reading comprehension or nonword reading and the correlation with reading recognition was substantially reduced (r = .26). Dillon and Pisoni (2006, p.139) concluded that "these findings suggest that the development of robust phonological representations and phonological processing skills underlies the development of reading skills in children who are deaf and use cochlear implants."

Dillon and Pisoni (2006) argue that if their measure of lexical diversity reflects vocabulary knowledge then children with a larger vocabulary should have more robust [well-specified] phonological representations and subsequently better reading outcomes. This argument assumes that children with larger vocabularies have expanded their vocabularies by phonological encoding of spoken information. Such an assumption may not be true for all children with a significant hearing loss, who may expand their vocabularies via visual – semantic processing. The children in the Dillon and Pisoni study were from a variety of communication approaches that included children who use a visual component in their communication (e.g. TC). Therefore it is possible that some of the children with the larger vocabularies had poorly specified phonological representations. As discussed above (see pages 90 & 91), Pisoni et al. (1999) reported no difference between the vocabularies of star and poor performers.

The Dillon and Pisoni (2006) study provides preliminary evidence that reading might be related to the phonological processing abilities in children using a cochlear implant. However, there are a few methodological limitations of the study. Firstly, only one measure of an aspect of phonological processing was used, namely a non-standardised measure of nonword reading accuracy. It is therefore unknown how the nonword repetition abilities of the participants compare to those of children with normal hearing. Secondly, children who were unable to complete the nonword repetition task were excluded from the study, which may give a positive bias to the results. Thirdly, while correlation coefficient and partial correlation coefficients were reported, there was no information to verify the assumption of linearity of these relationships. For example, a significant correlation was reported between age of onset of deafness and nonword repetition scores. However the large majority of participants in the study were *congentially* deaf, and therefore this relationship is unlikely to be linear. In addition there is evidence to suggest that in children with normal hearing with speech difficulties, nonword repetition scores are not related to vocabulary (Sutherland & Gillon, 2005). The quality of underlying lexical phonological representations may be better assessed by the use of a broad spectrum of tools thought to tap the underlying phonological representations, including a measure of phonological awareness. Dillon and Pisoni (2006, p. 140) concluded "additional research is needed on the relative contributions of various phonological processing skills (e.g., phonological awareness, phonological working memory skills, lexical access) to reading skills in children who are deaf and use cochlear implants".

2.5. Phonological Processing and Method of Communication.

The participants in the research to date on the phonological processing abilities of children using a cochlear implant have typically used a variety of communication approaches. There is virtually no information on the phonological processing abilities of oral communicating children using a cochlear implant who have received auditory-verbal therapy (AVT). Auditory-verbal practice adheres to the normal sequence of developing communication skills. Parents who adopt an AV approach to their child's communication development are specifically taught techniques to develop their child's listening skills such as adapting the environment to optimize listening conditions, focusing the child to listen and taking advantage of natural occurring learning opportunities. In addition, the types of words and phrases that are typically introduced are specifically chosen to develop inner phonological representations in a similar hierarchy as in the development of normal hearing children. AVT techniques that are used to develop speech and language skills through listening, attempt to encourage children to progressively attend to the fine distinctions of speech, such that they may eventually identify words based on the specific acoustic features (place, manner and voicing) of segmental information (Edwards & Estabrooks, 1994). Initially, words high in suprasegmental information are introduced and parents are asked to acoustically highlight important information. Words and phrases high in acoustic information are introduced first because it is believed that in the hierarchy of spoken word discrimination, grosser features such as syllable or vowel length are easier to discern than individual segments of speech such as the phoneme. The aim is that with practice the child with a hearing loss will be able to develop their listening skills and identify words at a segmental level, and in a reciprocal process expand their vocabulary and make finer phonemic distinctions between words and sounds.

A principle of auditory-verbal practice (see Appendix C for principles of auditory-verbal practice) is to develop the child's speech feedback loop so that they may monitor their speech and self correct with reference to correct models. A technique for developing this skill is to ask the child: *What did you hear?* In asking this question the child is prompted to engage in verbal rehearsal to keep the message active in phonological working memory in anticipation of being required to repeat what they have heard. It is possible that children with a hearing loss who have learnt to discern the fine differences in auditory information have better phonological encoding skills and more richly specified phonological representations in their long-term memory than children with a hearing loss who have developed communication via a visual modality or with less focus on listening skills. There are no known studies that have reported on the reading and phonological processing skills of a group of children that have participated in AVT.

2.6. Summary: Chapters 1 and 2

The extensive review of the literature in chapters 1 and 2 has attempted to capture the current state of knowledge about reading, speech perception, speech production, language and phonological processing abilities of children who use a cochlear implant. At the beginning of chapter 1 it was noted that on average children with a hearing loss have achieved reading proficiency no greater than the fourth grade, however there is a large range in performance across children across an array of variables. The variables thought to be associated with different outcomes for skills such as speech and language have implicated length of implant use, age at implantation, communication mode and MAPping strategies used, to name a few. Of the majority of the research that has explored the relationship between reading, and speech production, language, and phonological processing the participants have been drawn from the same cohort of children within a range of American educational settings (e.g., Burkholder & Pisoni, 2003; Carter et al., 2002; Cleary et al., 2002; Cleary, Pisoni, & Geers, 2001; Dillon et al., 2004a; Dillon et al., 2004b; Dillon & Pisoni, 2006; Geers, 2003, 2004; Geers et al., 2003a; Geers et al., 2003b; Pisoni & Cleary, 2003; Pisoni et al., 1999; Tobey et al., 2003) .

The trend for children receiving a cochlear implant in Australia, as is in many countries, is for younger implantation, use of recent technology, attendance at a mainstream school and development of communication via an auditory-verbal approach. However, relatively little is known about the impact of such trends on children's developmental ability, particularly as they relate to reading and the skills known to influence reading from the literature on children with normal hearing. Currently there is little known about the phonological processing abilities of children using a cochlear implant who are oral communicators in mainstream education, and there is no comprehensive information regarding how the phonological processing abilities of children using a cochlear implant compare to the skills of children with normal hearing. Further, there is no information regarding these skills in Australian children using a cochlear implant. An investigation of a range of phonological processing abilities would provide important insight into how these skills do or do not contribute to reading outcomes for children who use a cochlear implant. For such an investigation to be meaningful the broader range of skills thought to contribute to good reading outcomes including speech production, speech perception, language, and demographics need to be considered. The studies reported in this thesis address the need for such a thorough and comprehensive investigation.

2.7. Research Aims and Questions

There are two main aims of this thesis. The first aim is to provide comprehensive profiles of the reading and phonological processing abilities of school-aged children who use a cochlear implant and communicate orally. The second is to explore what skills might be related to reading outcomes and to present a big picture view of the relationships between the children's performance on tasks of reading, speech perception, speech production, language and phonological processing. To achieve the two broader aims a series of studies were conducted to address the following questions and hypotheses emerging from the extensive review of the literature:

1. What are the reading (word reading and reading comprehension) outcomes for oral communicating children using a cochlear implant?
2. What demographic and implant-related factors relate to reading outcomes for oral communicating children using a cochlear implant?
3. What are the speech perception, production and language profiles of oral communicating children using a cochlear implant?
4. What are the phonological processing (phonological working memory, phonological awareness and phonological retrieval) abilities of oral communicating children using a cochlear implant?

   It is hypothesised that the participants (oral communicating children using a cochlear implant that have participated in AVT):

- will have better phonological processing abilities than children using a cochlear implant in previous research who have used more visual communication approaches.
- will have poorer phonological processing abilities than children with normal hearing because the participants do not have *normal hearing* and have experienced a period of auditory deprivation.

5. What are the relationships between reading and spoken language measures?

   It is hypothesised participants (oral communicating children using a cochlear implant that have participated in AVT):

   - with better word reading and language skills will have better reading comprehension outcomes.
   - with better phonological processing abilities will have better word reading outcomes.
   - with larger vocabularies will have better phonological processing abilities.

The method relating to all the above questions is described in chapter 3. The results and discussions are presented in chapters 4 to 7: questions 1 and 2 in chapter 4, question 3 in chapter 5, question 4 in chapter 6 and question 5 in chapter 7.

Chapter 3. Method

"Identifying the reasons for the wide variability in outcome measures after cochlear implantation is a challenging research problem because a large number of complex sensory, perceptual, cognitive and linguistic processes affect speech and language performance in any particular behavioural task."

(Pisoni & Cleary, 2003, p.106S)

3.1. Introduction

To address the two main aims of this thesis, a range of abilities in 47 children (aged 5 to 12 years) with a significant hearing loss using a cochlear implant and oral communication were profiled, and the relationships between the abilities were examined. The abilities chosen for investigation included speech (perception and production), oral language (receptive and expressive) and written language (word reading and reading comprehension) and phonological processing (phonological working memory, phonological retrieval and phonological awareness). The study controlled for a range of variables that previous research has shown can affect outcomes in each of these areas. These inclusionary criteria included age of onset of hearing loss, age at assessment, length of implant use, language of the home, mode of communication and type of education program. A single exclusionary criterion, absence of additional disabilities, was also included. In addition, the study collected data on a range of contributory variables. These variables were selected based on previous research in which they had been identified as having a significant association with outcomes achieved by either children with hearing loss or for typically developing children. Six contributory variables were identified: age of implantation, age of first hearing aid fitting, number of years using a cochlear implant, mother's educational level, gender and number of children in the family. This chapter describes the participants, tests used and data collection procedures for addressing the two main aims of this thesis.

3.2. Inclusion Criteria

3.2.1. Age of Onset of Hearing Loss and Chronological Age

Criteria:

- prelingual bilateral profound hearing loss
- school aged (>5 years - <13 years of age)

Rationale:

Children who were diagnosed with a significant hearing loss prelingually were included to provide a homogeneous cohort with respect to exposure to spoken language. This study aimed to investigate outcomes in reading and therefore only school-aged children who were at the chronological age where developmentally they should have acquired early reading or reading skills were included. An upper age limit of 12 years was adopted to exclude children who had used now obsolete implant processing strategies such as F0F2 and MPeak for a large part of their time using an implant.

3.2.2. Length of Implant Use

Criterion:

- had used a cochlear implant for at least 2 years

Rationale:

In the first year post implantation, the MAP can undergo frequent changes as the user becomes accustomed to the device (Hughes, Vander Werff, Brown, Abbas, Kelsay, Teagle, & Lowder, 2001; Shapiro & Waltzman, 1995). Participants were required to have used a cochlear implant for a minimum of 2 years and have a stable MAP. This criterium was also used to ensure that the children had a minimum amount of time to adjust to listening via the cochlear implant.

3.2.3. Mode of Communication

Criterion:

- oral English as first language

Rationale: Tasks used in this study included those testing phonological awareness abilities. Phonological awareness may develop differently for children whose first language is not English, particularly for non-alphabetic languages. In addition phonemes may be differentiated differently in other languages and therefore may influence a child's ability to complete phonemic awareness tasks in English (Waltzman, 2000). Further, the tests used in this study were in developed for English speakers, and had been standardised in English.

Criterion:

- children who are enrolled in an oral educational program

Rationale:

Previous studies with children with significant hearing loss have shown that communication mode may be a variable affecting speech and language outcomes (Geers et al., 2003a; Pisoni & Cleary, 2003; Tobey et al., 2003). Marschark, Rhoten & Fabich (2007) highlighted the importance of careful selection of participants, rather than using heterogeneous groups in studies of outcomes in children with hearing loss. To date much of the research on outcomes for children who use a cochlear implant has included children using diverse modes of communication, most typically TC and OC (see chapters 1 and 2) and from a variety of educational settings. This has been a limitation of previous research, because the influence of communication mode and educational approach on outcomes is uncontrolled. The current study selected participants who used oral communication. In addition, the study sought to circumscribe mode of communication by selecting children from a single implant centre (The Sydney Cochlear Implant Centre, SCIC). All children in this clinic participated in the same auditory-verbal program prior to and in the initial 6 to 12 months after receiving their implant.

3.3. Exclusion Criteria

3.3.1. Additional Disability

Participants who met the inclusionary criteria were excluded if they had a documented additional disability such as intellectual disability, oral motor difficulties, or moderate/severe cerebral palsy. Exclusion, based on of the presence of additional disabilities, was done using the child's medical records, which contained results of medical, educational and speech/language evaluations. The children admitted to the study had no documented additional disability. The absence of concomitant intellectual or motor impairment was corroborated by the researcher (a qualified and experienced speech-language pathologist) over the course of the assessment sessions with each child.

3.4. Contributory Variables

Data on a range of contributory variables were collected to determine their association with the outcome variables. These contributory variables included: age of implantation, age of first hearing aid fitting, number of years using a cochlear implant, gender, mother's educational level and number of children in the family. These variables were chosen because of previous research indicating a possible, but not definitive association with outcomes. This section provides justification for each of the selected contributory variables.

3.4.1. Age of Implantation

As discussed in chapter 1, better outcomes have generally found for those children implanted at a younger versus older age (e.g., Connor, Craig, Raudenbush, Heavner, & Zwolan, 2006; Connor & Zwolan, 2004; Dettman et al., 2007; Dowell et al., 2002; Geers, 2003; Hammes et al., 2002; Kirk et al., 2002a; Tye-Murray et al., 1995). However, in one study of reading outcomes in children implanted under 5 1/2 years (Geers, 2003) earlier cochlear implantation was not significantly related to outcomes.

3.4.2. Age of First Hearing Aid Fitting

Yoshinaga-Itano, Sedey, Coulter and Mehl (1998) compared the language outcomes of two groups of children with hearing loss (mild to profound): children with hearing loss diagnosed by 6 months of age (n=72) and children with a hearing loss diagnosed after 6 months of age (n=78). There was a very short time span between age of diagnosis and time of amplification fitting in the children in the study (average 1 – 2 months). Yoshinaga-Itano et al found that language outcomes were significantly better in children with a hearing loss identified prior to 6 months of age. Other studies of children with a hearing loss not using a cochlear implant have reported that an early age of first hearing aid fitting (prior to 6-months) is positively associated with outcomes (Markides, 1986; Robinshaw, 1995). However, studies of the reading outcomes of children using a cochlear implant (e.g., Connor & Zwolan, 2004; Geers, 2003; Spencer et al., 2003; Spencer et al., 1999; Vermeulen et al., 2007) have not considered the possible influence of this variable on reading outcomes.

3.4.3. Number of Years Using a Cochlear Implant

Length of time using a cochlear implant has been associated with better outcomes relative to children with a profound hearing loss using hearing aids (Tomblin et al., 1999), but both poorer (Connor & Zwolan, 2004) and improved outcomes relative to children with normal hearing (Geers, 2003) (refer to 1.3.1.2). Given there is no conclusive evidence regarding the influence of number of years using a cochlear implant on reading outcomes it was necessary to include this variable.

3.4.4. Gender

As reported in chapter 1, there have been different findings from the studies that have investigated the influence of gender of reading outcomes (Geers, 2003 versus Connor & Zwolan, 2004; Dillon & Pisoni, 2006). In a study attempting to explore and identify the main variables implicated in good reading outcomes, it was necessary to include gender.

3.4.5. Education Level of the Mother

Socio-economic status (SES) has been found to predict reading outcomes in children using a cochlear implant (Connor & Zwolan, 2004; Geers, 2003). However, the manner in which SES has been defined in the literature has differed. Indicators such as parents' income and education, as well as medical insurance have been used as indicators (Connor & Zwolan, 2004; Geers, 2003). The better reading outcomes for children from higher SES families have been attributed to factors such as the ability to attend MAPping appointments, and parents' attendance and participation in therapy (Connor & Zwolan, 2004; Geers, 2003). However these factors may vary for reasons other than SES. Children with normal hearing who have parents with higher educational levels have been found to have larger vocabularies than children whose parents have a lower educational level (Hoff & Tian, 2005), and the mother's educational level has been positively related to benefit from facilitative language programs (Yoder & Warren, 2001). In Australia at the time of this study, all children were eligible for a cochlear implant regardless of medical insurance, and government or other (e.g., volunteer, charity groups) assistance was given when required to help families with travel to medical appointments. At SCIC audiological, MAPping and therapy appointments were co-ordinated with medical appointments so that all participants could attend sessions based on child/family requirements rather than on financial ability to attend. Therefore, for this study level of mother's education was recorded as the measure of SES. Mother's educational level was coded as the number of years of education completed. For example, a mother completing Year 12 in NSW was credited with 13 years of education. When this information was not obtainable from the child's mother, information regarding the mother's occupation was used to determine years of education (for example, for a psychiatrist, years of education was assumed at 19 years; 13 years of school and 6 years of tertiary education). For three of the participants there was insufficient information to determine the mothers' years of education. For these participants the mean score for the other 44 participants was used (i.e., 14). Using the sample mean for missing scores is said to be a "standard strategy for dealing with missing data" (Rvachew & Grawburg, 2006, pp. 81 and 82) and has been used in other research (Rvachew & Grawburg, 2006). As a group SES status of the participants can be considered high with the majority of participants' mothers completing high school and having some tertiary education.

3.4.6. Number of Children in the Family

Only one known study has reported on the effect of family size on outcomes for children using a cochlear implant. As reported in chapter 1, Geers and Moog (2003) found better speech perception, speech production and language outcomes, but not better reading outcomes (Geers, 2003) for children from smaller families. The participants in the current study have different characteristics to the participants in the Geers study. There have not been enough studies investigating the effect of number of children in the family on outcomes to draw conclusions about the impact of this variable and therefore it was included as a contributory variable.

3.5. Participants

3.5.1. Recruitment

All participants were recruited from the Sydney Cochlear Implant Centre (SCIC), New South Wales, Australia. At the time of data collection, SCIC was the sole centre for pediatric cochlear implantation in New South Wales. As a consequence of this, participants from the study were drawn from the total population of children implanted in New South Wales. Cochlear implants like hearing aids are available free, under a federally funded hearing services program, to all Australian children who require them. The financial resources of the parents therefore do not skew the population of recipients.

All children who met the selection criteria were invited to participate in the study. The parents of all potential participants were sent a letter explaining the study and inviting his/her child to participate (see Appendix A). Parents who did not respond to this initial letter were followed-up by telephone. Fifty-seven children who met the selection criteria were identified and 47 agreed to participate, a participation rate of 82%. All parents gave written consent prior to testing (see Appendix B).

3.5.2. PARTICIPANT CHARACTERISTICS

Forty-seven children between the ages of 5;4 years and 12;6 years were recruited. Table 3-1 presents audiological and demographic information about the participants. The criteria for pediatric implantation at the time these participants received their cochlear implant were a bilateral, profound hearing loss in the best ear and/or aided hearing thresholds outside the speech range above 2000 Hz. All but one participant with available pre-implant information had a pure tone average above 90dB HL in their better ear. One participant with a bilateral precipitous loss had a pure tone average, based on their thresholds at 500, 1000 and 2000 Hz, of 82dB HL. Their threshold was 25dB HL at 500 Hz falling to 110dB HL at 1000 and 2000 Hz. Participants whose thresholds were greater than 110dB HL did not have a threshold recorded. The calculation of their pure tone average was based on using the upper limit of 110dB for that frequency. The pre-implant pure tone average was not recorded on file for three participants. For the purposes of data analyses, the three participants with no pre-implant hearing threshold data were assigned the mean pure tone average of the other 44 participants, i.e., 103dB HL.

Participants in this study were born before the introduction of universal neonatal hearing screening in NSW. The hearing-screening program in NSW has resulted in the average age of diagnosis of hearing loss falling from 18 months in the years before screening to 6 weeks. Similarly, the age of initial hearing aid fitting has fallen from 22 months to a current level of 3 months (NSW Department of Health, 2004). For participants in the current study, the median age for initial fitting of a hearing aid was 14 months and their median age for cochlear implantation was 33 months, with 25% of the participants receiving their implant before 2 years of age. There was only one participant implanted above 6 years of age. This participant had a congenital progressive hearing loss due to large vestibular aqueduct syndrome.

Table 3-1 General participant characteristics

Characteristic	*Mean*	*Median*	*Range*	*Standard Deviation*
Pre-implant PTA (dBHL)	103dB	105	82 – 110	7.69
Age at first hearing aid fitting in months	16 mo.	14	2 – 42	10.14
Age at CI activation in months	40 mo.	33	14 – 97	19.67
Years using CI	5.37yrs	4.92	2.25 – 9.83	1.93
Chronological age at reading & phonological processing assessment	8.75yrs	8.75	5.33 – 12.50	2.05
Chronological age at speech perception, speech & language assessment	8.74yrs	8.75	4.83 – 12.83	2.15
Years at school	3.91yrs	-	K – 7	2.03
Number of children in family	2.64	2	1 – 7	1.44
Mother's education (Yrs)	13.95yrs	14	5 – 19	2.80

Table 3-2 details the etiology of hearing loss for all participants and the type of cochlear implants and processing strategies used. The participants' etiology of deafness was categorized as congenital or acquired. Thirty-nine of the participants (83%) had a congenital hearing loss. Two participants with a congenital loss had a hearing loss as part of a syndrome (Pendreds and Wardenburg). Children identified with an acquired hearing loss had an etiology of meningitis, with pre-verbal onset. Eight of the participants (17%) acquired their hearing loss following meningitis.

All participants were using a Nucleus cochlear implant. Sixty-four-percent of the participants were using the Nucleus® 22 device with the Spectral Peak (SPEAK) processing strategy. The remaining 36% of participants used the Nucleus® 24 device with the option of either the Advanced Combination Encoder (ACE) or the SPEAK processing strategy. Five participants fitted with the Nucleus® 24 used SPEAK while 12 used ACE. The current health policy in NSW is that the additional benefits of the Nucleus® 24 are not sufficiently great to recommend explant of the Nucleus® 22 and reimplantation with the Nucleus® 24. All new implants are Nucleus® 24 devices.

Two participants whose devices were switched on in 1991 initially used MPEAK, an earlier strategy than SPEAK, and were changed to SPEAK 3.5 years later in 1995. They had been using the SPEAK processing strategy for 5 years before the commencement of this study.

Forty participants in the current study had a full or near full array of active electrodes. The number of active electrodes was not documented for 7 participants. A reduced number of active electrodes have been associated with poorer outcomes for some measures for cochlear implant users. Geers, Brenner et al. (2003a) reported that number of active electrodes independently contributed to some of the variance in speech perception scores. However number of active electrodes did not significantly contribute to reading outcomes (Geers, 2003).

Table 3-2 Participant characteristics: Etiology and implant device profile

Characteristic		*Number of participants*
Etiology:	Congential	39
	Pre-verbal meningitis	8
Implant device:	Nucleus® 22	30
	Nucleus® 24	17
Processing strategy:	SPEAK	35
	ACE	12

Geers (2003) suggested factors such as number of electrodes, device and strategy, and dynamic range, are associated with outcomes for cochlear implant users. These factors were not included as independent variables in the analyses in this research because implant device and processing strategy factors were relatively homogeneous for the participants. The majority of the participants used the Nucleus® 22 device (31/47) and the SPEAK processing strategy (35/47).

The appropriateness of a child's MAP can affect the quality of the auditory signal they receive, and therefore their outcomes (Waltzman, 2000). There are a number of parameters that can be individualized in the creation of a MAP such as appropriate T (threshold) and C (comfort) levels, mode of stimulation, rate of stimulation, frequency-to-electrode allocation (Waltzman, 2000). It is beyond the scope of this study to investigate the subtleties of the participants' MAP. However, following cochlear implantation the participants' MAPs were created and modified by experienced paediatric cochlear implant audiologists. Participants in the study had regular 6-monthly or yearly MAPping appointments, and if the child or their parents were ever concerned about the quality of their MAP it was the SCIC policy that a MAPping appointment would be promptly arranged. The participants' MAPs were therefore considered to be clinically adequate. Dynamic range was not used as a variable due to the inherent difficulty with defining an appropriate way to calculate dynamic range. To take an average of the dynamic ranges across all electrodes is not a valid representation as some MAPs can have great variability between dynamic ranges on different electrodes when others have consistent ranges across electrodes. Further, all the participants in the study had dynamic ranges over 20 units on the smallest range (dynamic ranges typically ranged from about 30 to 80 units across electrodes).

Table 3-3 presents data about the school grade and educational placement of the participants. Information regarding the participants' school placement and year, number of children in the family, and mother's educational level was obtained directly from the participants' mothers or caregivers. None of the participants had any documented additional disabilities such as intellectual disability, oral motor difficulties, blindness, or moderate/severe cerebral palsy.

Table 3-3 Participant characteristics: Education grade and schooling approach

	Characteristics	*Number of participants*
School grade:	Kinder***	6
	1	7
	2	9
	3	9
	4	7
	5	3
	6	4
	7	2
Schooling approach	(a) mainstream only	43
	(b) mainstream and school for hearing impaired	2
	(c) oral unit within mainstream school	2

***Kinder = kindergarten which is the first year of school in NSW, at 5 years old.

The cochlear implant centre (SCIC) had a protocol that required the children and their parents to attend weekly auditory-verbal therapy (AVT) sessions in the pre- and post-implant period. The duration of the AVT sessions varied according to individual needs. The pre-implant phase typically lasted 3 to 6 months after optimal hearing aid fitting and compliance was achieved[13]. Exception to this protocol was made in the case of children whose hearing loss resulted from the contraction of meningitis. In these cases the urgency of implantation prior to the onset of ossification generally resulted in a very short pre-implantation phase. The post-implantation phase in which weekly AVT sessions were conducted was typically for 6 to 12 months post-implantation. In addition all participants were enrolled in an educational program with an oral/aural focus. At the time the participants in this study were implanted, the SCIC referral criteria stated that children should be "in an education program that focuses on the development of communication skills through an oral/aural approach"[14] (The Children's Cochlear Implant Centre, 1996, p.5). The participants were required to have educational support that adhered to the principles of auditory-verbal practice prior to discharge[15]. The quality and type of input following discharge from the acute stage at SCIC cannot be accurately determined due to the participants' encounters with a range of teachers and educational programs over the years since discharge.

The majority of the participants, 91.5%, were fully integrated in a mainstream

[13] The duration of the pre- and post-implant phase has since changed. The length stated refers to the practices at the time children in the study were implanted.

[14] The SCIC referral criteria for cochlear implantation have since changed. Recently children from all communication approaches including TC and Sign are accepted for cochlear implantation.

[15] The SCIC discharge criteria have also changed since the children in this study were in the post-implantation phase and more recently the parents informed choice of educational approach is encouraged.

school or preschool. Two participants, 4.25%, were in a school for the hearing – impaired with an auditory focus and another two participants, 4.25%, were in an oral class for children with a hearing-impairment within a mainstream school. Participants in the last two settings had daily integration into a mainstream school.

3.6. Data Collection

3.6.1. General Procedures for Administration of Tests

All testing took place in quiet clinic rooms at SCIC. Parents were asked to make sure their children came with the cochlear implant processor that the child used at school. Some participants had both a body worn (Nucleus® 22: SPECTRA or Nucleus® 24: SPRINT) processor, and a behind the ear (BTE) processor. The body worn processor was generally the preferred educational device. If the child used glasses for reading they were asked to bring these.

Tests of reading, speech perception, speech production, language and phonological processing were administered to obtain measures of participants' abilities within each of these skill areas (refer to Table 3.4). The language and speech perception tests were completed on the same date as part of the participant's annual assessment review. Other tests, including tests of phonological processing, speech production and reading were done in a separate session, scheduled within 1 month either before or after their speech perception and language assessment. When this was not possible the closest dates for the appointments were used. The average time between the two assessment sessions was 2.49 months (SD = 2.28), and 85% of the participants (40/47) completed the two assessment sessions with a maximum time interval of 4 months. If a child showed signs of discomfort or fatigue during a test session, the session was discontinued. This resulted in not all participants completing the full battery of tests.

Appendix D shows the number of participants who completed each test.

The researcher, a qualified speech pathologist experienced in assessing children with a significant hearing loss, administered all reading, phonological processing and speech production tests. For these tests, the researcher sat facing the child on their implanted side, at a distance of approximately 50cm from their microphone. The tests were administered in a single session of no more than 2 hours with frequent breaks given as required. Practice items were administered in accordance with test manual instructions to ensure that the participants understood the instructions of the tasks. The order of test presentation was randomized for each child, with the exception of the adapted ACAP, which was always administered as the final test. Another test, the QUIL nonword reading subtest, was not given if the child was fatigued. The QUIL is a non-timed test and covered a similar ability area as the primary timed nonword reading test in the battery (the TOWRE) and was included to compare results of the different tasks.

Participant responses were recorded on-line. The testing sessions were also video-taped and reviewed by the researcher within 48hrs to review and record any responses missed online. Inter- and intra-rater reliability of test form scoring was conducted on a random sample of 10% (5/47) of test forms. In total scoring for 450 items was checked. Both inter-rater reliability and intra-rate reliability were 100%.

The tests of language were administered in a separate session by the researcher or other qualified speech pathologists experienced in assessing children with a hearing loss. The language tests were all standardised tests and were administered using the standard protocol. The assessments were presented in live voice in a quiet clinical room at SCIC and the participants were able to use lip-reading cues. The examiner sat approximately 50 cm from the participant's implanted ear, in keeping with the administration procedure for the reading, speech production and phonological processing tests.

The speech perception tests were administered by a qualified audiologist experienced in assessing children with a hearing loss. The audiologists transcribing the speech perception tests used in the present investigation also participated a study by Blamey et al. (2001) using the same assessment tools. Blamey et al. (2001) reported low inter-transcriber variability for BKB sentences, CNC words and phonemes, although they reported that the test-retest variability was about twice that of inter-transcriber variability. All participants in the present study were familiar with the speech perception tasks that are administered annually as part of their standard assessment. The speech perception tests were administered either in a quiet clinic room or in a sound-treated room. For live voice tests, the audiologist was seated at a distance of 1 meter from the participant centrally facing the child and using a hand, angled at 45 degrees out from between their top lip and nose, to cover their mouth (a technique routinely used in AVT). This ensured that their lips were not visible and their speech was not muffled or distorted. The live voice tests were presented at loud conversational level of approximately 65 – 70 dB SPL. For recorded speech perception tests, the child sat 1 meter from the speaker and the speech signal was calibrated for presentation at 65 dB SPL at the ear of the child.

3.6.2. Test Description, Rationale and Administration

Standardised tests were selected if available in order to accommodate the age range of the participants, enable comparison of the participants' outcomes with their normal hearing peers as well as comparison of scores on different subtests and tests. However, the population sample on which the standardisation occurred should be comparable to avoid misrepresentation (Anastasi & Urbina, 1997; Lahey, 1988).

Obviously for subtest comparisons this is not an issue. In choosing the tests to use for inter-test comparisons, where possible tests that have used a standardising sample for populations with similar characteristics were chosen. Tests standardised on children with normal hearing were considered to be appropriate because the participants were enrolled in a mainstream school setting[16], and were therefore learning alongside peers with normal hearing. These tests also allow meaningful comparison with hearing peers. Several of the tests were standardised on American children. These tests were included in the overall test battery because Australian norm-referenced tests with the same attributes did not exist. The use of American norm-referenced tests in the absence of an Australian equivalent is customary practice in Australia.

Appendix E provides a summary of the key psychometric characteristics for each of the tests. Table 3-4 summarizes the tests used to measure the specific skill areas of interest. The section following provides a description of each test and the rationale for its inclusion in the test battery.

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[16] For 4 participants this was only partial integration with the view to full integration.

Table 3-4 Summary of tests used to measure each outcome area

Domain	*SUB-DOMAIN*	*Test*
Reading	**(a) Word Reading**	
	- sight word reading efficiency	Test of Word Reading Efficiency (TOWRE)
	- nonword reading efficiency	Test of Word Reading Efficiency (TOWRE)
	- nonword reading	Queensland University Inventory of Literacy (QUIL)
	- passage reading accuracy	Neale Analysis of Reading Ability-3rd Ed (Neale-3)
	(b) Reading Comprehension	Neale Analysis of Reading Ability-3rd Ed (Neale-3)
Speech Perception	**(a) Word level**	Consonant-Nucleus-Consonant Word Test (CNC)
	(b) Sentence level	Bench-Kowal-Bamford Sentences (BKB)
Language	**(a) Receptive vocabulary**	Peabody Picture Vocabulary Test 3rd Ed (PPVT –3)
	(b) Receptive and expressive language	Clinical Evaluation of Language Fundamentals – 3rd Ed. (CELF-3) and Preschool Edition (CELF – Preschool)
Speech Production	**Single-word production of mono, di-, and polysyllabic words.**	Assessment of Children's Articulation and Phonology – Adapted (ACAP-A)
Phonological Processing	**(a) Phonological Awareness**	Comprehensive Test of Phonological Processing (CTOPP)
	(b) Phonological Working Memory	Comprehensive Test of Phonological Processing (CTOPP)
	(c) Phonological Retrieval	Comprehensive Test of Phonological Processing (CTOPP)

3.6.2.1. *Outcome Area: Reading*

Neale Analysis of Reading Ability-3rd Ed.

Description

The Neale Analysis of Reading Ability-3rd Edition (Neale-3) (Neale, 1999) is an Australia norm-referenced test and was chosen to provide information on the participants' oral word reading and reading comprehension skills for passage length material. The format is narrative passages with accompanying picture line drawings.

The Neale-3 can be used with all age groups (Neale, 1999). However the standardisation was performed on children aged between 6 years to 12;11 years. The norms use year of schooling (YOS) rather than chronological age. The authors report that this was done to account for the variations in age of commencement of schooling across Australian states. In NSW children start in Year K, which means in Year 3 they are in their fourth year of schooling, therefore YOS = 4. The psychometric characteristics of the Neale-3 indicate it is a relatively stable, consistent and accurate test of reading ability.

Rationale for Inclusion

The Neale-3 provides separate measures of word reading accuracy, text level reading comprehension and reading rate for passage length material, thereby giving coverage to the major component skills for reading.

The passage length material for text reading comprehension mimics typical book reading and classroom reading comprehension activities and adds to the face validity of the test.

The Neale-3 was normed on an Australian population and is recent, with the latest norms being developed in 1997. Text reading comprehension may be influenced by social experience and familiarity of language (Johnson, 1982; Pritchard, 1990) so the currency of the Neale-3 helps to control for this factor.

Standardised administration procedures for the Neale-3 allow limited prompting if a child has difficulty with word reading. This is done to limit as much as possible the interdependency of word reading and reading comprehension, and to derive separate measures of each skill.

Administration

The standard procedure for administration as described in the Neale-3 manual was followed. The participants read an age-appropriate practice passage and answered questions about that passage. This familiarized the child with the type of passage and the format of questions in the test. The participants then read a series of short passages of increasing difficulty in vocabulary, syntactic complexity and length. After each passage they were asked a series of questions about it. The time taken to read each passage was recorded and any errors in pronunciation were also recorded and categorized.

The Neale-3 standardisation uses year of schooling (YOS). The children in YOS 1 in NSW schools are between the ages of 5 and 6+ years. The manual states that, "time of intake and age of intake should be borne in mind when interpreting score. NSW has a single intake at the beginning of the school year and the cut-off for entry to school is age 5 by 31 July" (Neale, 1999, pp.26 & 28). The participants in this study were allocated to a YOS based on their age at the time of assessment. Refer to Appendix E for YOS allocations. If a research participant was unable to do the Neale-3 and was over 6 years of age (i.e., an age that they should be able to attempt the test) then a standard score of 0.1 was given. A score of just above 0 was given to eliminate the occurrence of zero scores in the statistical analysis, as zero scores can result in the participant not being included in the analysis.

Test of Word Reading Efficiency (TOWRE)

Description

The TOWRE (Torgesen, Wagner, & Rashotte, 1999a) is a standardised test that measures the speed of reading single words. Top-down processes such as prediction from sentence context and deduction are therefore not available in the TOWRE as they are in the Neale-3, which uses passage length material. The TOWRE is a timed task and therefore measures a child's ability to read efficiently, that is, both accurately and fluently. The TOWRE tests sight word reading efficiency through the use of familiar words, and phonemic decoding efficiency through the use of nonwords.

Rationale for Inclusion

The TOWRE provides a measure of a key area of the study, namely word reading efficiency. The inclusion of separate measures of sight word reading and nonword reading provides information about the participants' skills in utilizing both an orthographic and phonemic decoding route to reading.

The TOWRE is a standardised assessment providing standard scores based on chronological age. The use of standard scores allows comparison between sight word reading efficiency and phonemic decoding efficiency as well as comparison with other standardised tests in the battery of assessments.

The TOWRE is reliable and quick to administer taking approximately 5 minutes. Given the number of tests administered in the assessment battery the quick administration was a favourable characteristic. The TOWRE reliability coefficients with respect to subtest and total scores for content sampling, time sampling and inter-scorer differences were all equal to or above 0.90. These high reliability coefficients suggest that the TOWRE is a consistent measuring tool with little internal error variance.

Administration

The TOWRE was administered according to standard procedures as described in the manual. The reading cards for Phonemic Decoding Efficiency (PDE) and Sight Word Reading Efficiency (SWE) - Form A or B - were administered alternatively. The method for scoring as described in the TOWRE manual was followed (Torgesen et al., 1999a). That is, a raw score was the correct number words (SWRE) or non-words (PDE) read with acceptable pronunciation[17] in 45 seconds. Raw scores for both sections (SWRE and PDE) were obtained and then converted to standard scores using the age-based normative tables in Appendix A of the TOWRE manual.

Queensland University Inventory of Literacy (QUIL)

Description

The Queensland University Inventory of Literacy (QUIL) (Dodd, Holm, Oerlemans, & McCormick, 1996) is an Australian developed test that provides measures of phonological awareness and nonword reading skills. Only the nonword reading subtest was used in the present study.

Rationale for Inclusion

The QUIL nonword reading subtest is similar to the phonemic decoding efficiency subtest of the TOWRE. However the QUIL is not timed and the norms are based on school year rather than chronological age. The QUIL therefore measures accuracy, but not efficiency. The QUIL was included in the present battery to enable

[17] Acceptable pronunciation for non-words as described in the manual is "most common or regular pronunciations for consonant – vowel sequences" (Torgesen et al., 1999, p. 22). This definition was adhered to, however, it was applied to standard Australian English pronunciation. For example, Table 3.1 in the TOWRE manual lists acceptable pronunciations for 'ta' as /teI/ & /tae/. In Australian English the acceptable pronunciations are /ta/ and /tae/.

comparison with the timed test of nonword reading (TOWRE).

Administration

The nonword reading subtest of the QUIL was administered according to the standard procedure described in the manual. The list of nonwords was given to each participant to read aloud and their verbal responses were recorded on-line as either correct or incorrect. The method for scoring as described in the QUIL manual was followed. The raw score was converted to a standard score using the grade (year of schooling) based normative tables (see Appendix F for assignment to YOS level, based on participant's age).

3.6.2.2. Outcome Area: Speech Perception

Speech perception tests are used clinically in audiology to assess a user's ability to detect and recognise the speech signal. Typically the speech stimuli are familiar single words or short sentences. While recoded speech tests give greater reliability these are not typically used with young children because of the loss of flexibility in administration. Live voice tests enable the tester to ensure the child is listening before presenting each stimulus. To improve reliability, live voice tests are administered using a sound level meter to monitor variations in level of presentation of stimuli.

Consonant-Nucleus-Consonant (CNC) Word Test

Description

The CNC test (Peterson & Lehiste, 1962) is an open-set monosyllabic (CVC) word test in which each initial consonant, vowel and final consonant appears with the same frequency of occurrence in each of the 10 lists. Each list consists of 50 words. Each list can be scored for the number of phonemes correct and the number of words correct.

Rationale for Inclusion

The CNC test is an open-set test and therefore requires the listener use primarily auditory cues to identify the word. It is commonly used in Australian implant centres in their assessment battery as a measure of speech perception ability, and has been also been used in cochlear implant research studies (Blamey et al., 2001; Psarros et al., 2002; Sarant et al., 2001).

Administration

The tester selected a CNC test list that the child had not been given in previous years. Word lists were presented auditory alone, that is, with no visual cues. Administration was either using monitored live voice or using a recorded version. For both conditions the presentation level was 65dB SPL. After each stimulus was presented the child repeated the word. The tester scored the responses online. Both word and phoneme scores were calculated. For example, a response of 'harm' to the stimulus 'farm', would score 2 out of 3 phoneme points, but 0 out of 1 word points. Results were recorded as percentage correct scores. The tester asked the child to repeat their response if they were unsure about any of the phonemes. Despite this caution, the scores on this test may be affected by a child's speech errors.

Bench-Kowal-Bamford (BKB) Sentences

Description

The BKB test (Bench, Doyle, & Geenwood, 1987) is a sentence test that uses language typical of the population of children with profound hearing loss. It is an open-set test and consists of 21 lists of 16 sentences. Each sentence is a maximum of 7 syllables in length. Each list contains 50 key words that are scored for accuracy to give a percent correct score for the list.

Rationale for Inclusion

This test is commonly used in Australian implant centre assessment batteries as a measure of speech perception ability and has been used in several other studies regarding individuals using a cochlear implant (Blamey et al., 1992; Blamey et al., 2001; Dowell et al., 2002). It provides a measure of the child's ability to recognize words using auditory cues as well as sentence context. The effects of vocabulary and syntactical knowledge are constrained by the use of stimuli taken from the productive vocabulary of children with profound hearing loss, and commonly occurring simple sentence structures.

Administration

The tester selected a sentence list that the child had not been given in previous years. Sentence lists were presented in the auditory alone condition either using monitored live voice or via a recorded CD. For both conditions the presentation level was 65dB SPL. The participants' responses were scored online. Only target words were scored, however speech errors were accepted if the pronunciation of the word was reflective of the child's general speech errors, the tester was confident the child's attempt was the target word and it contained all the morphological components of the target word. Results were recorded as percentage words correct.

3.6.2.3. Outcome Area: Speech Production

Assessment of Children's Articulation and Phonology (ACAP) (James, in preparation) – Adapted

Description

The ACAP is a test of speech production designed to account for possible differences in speech accuracy for words of different syllable length. Part one of this test contains 166 stimulus words that are monosyllables, disyllables or polysyllables. The ACAP manual has not yet been published and the test presentation booklet and scoring forms were obtained from the author.

The large number of items in the ACAP meant that it was unsuitable for the current study. Therefore an adapted version of the ACAP was developed which used 13 monosyllabic words (MSW), 7 disyllabic words (DSW) and 18 polysyllabic words (PSW) from the original ACAP word list. In the present study the monosyllabic and disyllabic words were grouped and labeled mono- disyllabic words (MDSWs). The PSWs consisted of 14 three-syllable words, 3 four-syllable words and 1 five-syllable word.

The words were selected to equate as much as possible the phonetic content across the two groups (MDSWs and PSWs), particularly for word initial consonants and clusters. Table 3-5 reports the occurrence of word initial sounds for the two groups. The stimulus words are presented in Appendix H. As normative data were not available the percentage of words correct was used to score skill at producing MDSWs (x/20), PSWs (x/18) and total words correct (TWs) (x/38).

Rationale for Inclusion

The ACAP includes PSWs (39 of the 166 items) whereas most of the currently published speech production tests contain predominately monosyllabic (MSW) and disyllabic (DSW) words. Polysyllabic picture naming tasks are thought to provide information on the status of the underlying phonological representations (James, 2006; Katz, 1986). James et al recommended, based on their preliminary standardisation data, that "speech testing of children 5 years and more must include significant numbers of polysyllabic words" (James et al., 2002, p.295). James (2006) further suggested that picture naming tasks that contain more than five PSWs can identify children with reading difficulties (James, 2006).

Administration

The ACAP two-dimensional colour pictures that matched the chosen stimulus items for the adapted test were presented in the order that they occurred in the original test. This meant that MDSW and PSWs were presented variably throughout the test and not blocked. The participants in the study were shown the picture and asked to name the picture. If they could not do this spontaneously, standard procedures for administration of picture naming tests were used and the participants were prompted, firstly by a description of the item, then given a binary choice and lastly if they still did not produce the word the name was given. To avoid immediate imitation the participant was asked 'What is it?' after being given the name. For example, 'It's a stethoscope, what is it?' The participants' responses were transcribed online using broad phonetic transcription and the administration was also videotaped to enable the examiner to later review the responses when there was uncertainty regarding pronunciation. The transcriptions were used for individual reporting of results and description of responses. In addition, five of the tapes (10%) selected randomly were later viewed by the author and another experienced speech pathologist to obtain intra-rater and inter-rater reliability measures. Intra-rater reliability was 98% and inter-rater reliability was 98% on point-by-point scoring (i.e., 190 items). As expected reliability ratings were high as only one examiner administered the test and responses were scored as either correct or incorrect for use in the analyses for this research. Any responses that were not an acceptable Australian pronunciation were scored as incorrect. The percentage of correct responses was calculated for MDSWs and for PSWs. The total number of words correct was also calculated.

Table 3-5 Number of initial consonants/clusters for MDSWs and PSWs in the adapted ACAP.

Word Initial Consonant Cluster	*Mono- Disyllabic Words*	*Polysyllabic Words*
/b/	1	1
/s/	1	1
/h/	2	2
/k/	2	1
/m/	1	-
/t/	2	2
/l/	1	-
/p/	1	1
/Z/	1	1
/dZ/	2	-
/st/	-	1
/pl/	1	-
/bl/	1	-
/sp/	1	1
/br/	-	1

3.6.2.4. Outcome Area: Language

Peabody Picture Vocabulary Test – 3rd Edition (PPVT-3)

Description

The Peabody Picture Vocabulary Test (3rd Edition) (PPVT-3) (Dunn & Dunn, 1997) is a standardised test for individuals from 2½ years upwards. The test measures receptive vocabulary using a picture pointing 4-alternative response task. The pictures are black and white line drawings.

Rationale for Inclusion

The PPVT-3 is a quick and relatively easy test for a qualified speech pathologist to administer and score. It requires no verbal response, reading or writing ability. These characteristics favoured its selection as part of the language test battery, as the impact of other skills such as speech production errors that might impede a child's ability to respond were limited. The PPVT-3 is not a timed test and uses criteria to discontinue testing. It typically takes approximately 12 minutes to administer. The PPVT-3 was developed and normed in the United States of America. However it is used by

Australian speech pathologists to identify language disorders in Australian children, and has been used in a number of Australian research studies with children with a hearing loss (Blamey et al., 2001; Wake, Hughes, Poulakis, Collins, & Rickards, 2004).

Administration

The PPVT-3 was administered using the standard procedures as described in the PPVT-3 manual. Recording Form B was used for all participants. The only deviation from the standard procedure was the determination of starting set. This was based not only on chronological age, but also an estimate of the participant's ability using the previous year's test results. The administration time varied between 5 and 25 minutes to complete the test. The participants' responses were recorded on-line on the record form as either correct/incorrect. The raw score was converted to standard score using the appropriate age tables. Some participants performed at a level below the lowest standard score of 40. The standard score for these participants was recorded as 40 for analysis purposes.

Clinical Evaluation of Language Fundamentals

Description

The CELF-3 (Semel, Wiig, & Secord, 1995) and CELF – Preschool (Wiig, Secord, & Semel, 1992) are comprehensive standardised language assessments that provide a measure of aspects of receptive and expressive language "generally regarded as fundamental to effective oral communication" (Semel et al., 1995, p.89). The CELF-3 was designed for individuals between the ages of 6 years to 21;11 years. The CELF-Preschool is a downward extension of the CELF-3 and provides a measure of receptive and expressive language for a younger age group (3 years to 6;11 years). Both versions of the CELF have six core subtests: three core receptive language and three core expressive language subtests. The CELF-3 consists of 10 subtests that target specific areas of receptive or expressive language, and it is dependent on the age of the child as to which core 6 subtests are administered.

Rationale for Inclusion

Both CELF editions are valid and reliable tests that provide a measure of a child's expressive, receptive and overall language skills as well as skills in specific linguistic areas. They are standardised assessments, which allow for relationships with abilities measured on other standardised tests to be explored as well as comparison with their age peers with normal hearing. Both editions are well-recognised tools internationally, have been used in research studies of children with hearing loss (Blamey et al., 2001; Dawson, Busby, McKay, & Clark, 2002), and are used by Australian speech pathologists to identify language disorders. Both CELF editions have age-appropriate pictures and stimuli that generally gain a child's interest.

Administration

Both editions of the CELF were using the standard procedures as described in the manuals. The subtests were administered in the order as shown in Table 3-6.

Table 3-6 Order of subtest presentation for CELF-3 and CELF Preschool.

CELF Preschool:	*CELF – 3* *7 years to 8 years 11 months*	*CELF – 3* *9 years and above*
Formulating Labels	Sentence Structure	Recalling Sentences
Basic Concepts	Word Structure	Word Classes
Sentence Structure	Word Classes	Sentence Assembly
Linguistic Concepts	Concepts and Directions	Concepts and Directions
Recalling Sentences	Recalling Sentences	Semantic Relationships
Word Structure	Formulated Sentences	Formulated Sentences

The procedure described in the manual for establishing ceiling levels was followed. The participants' responses were recorded on-line on the record form as either correct/incorrect, except for the recalling sentences and formulated sentences subtests, which were scored as described in the manual with 0, 1 or 2 points awarded as appropriate. The participants in this study generally took between 45 to 60 minutes to complete the 6 subtests. Participants' raw scores for each subtest were converted to standard scores using the conversion tables provided in the manuals. Composite scores were of primary interest in this study and expressive and receptive and total language composite scores were calculated.

3.6.2.5. Outcome Area: Phonological Processing

Comprehensive Test of Phonological Processing (CTOPP)

Description

The CTOPP (Wagner et al., 1999) is a standardised test that provides a measure of an individual's phonological awareness, phonological working memory and phonological retrieval skills. The CTOPP provides norms for individuals between the ages of 5 years and 24;11 years. There are two versions of the CTOPP. The first version was devised for children aged 5 years to 6;11 years. The second version was devised for individuals aged 7 years to 24;11 years. The different aspects of phonological processing are divided into various component skills, which are examined via subtests. The core subtests are used to formulate composite scores of the three relevant aspects of phonological processing: phonological awareness, phonological working memory and phonological retrieval (rapid automatised naming).

Phonological Awareness Composite

The phonological awareness composite provides a measure of a participant's overall awareness of and ability to manipulate the sound structure of English. The CTOPP covers specific tasks of phonological awareness (e.g., elision, blending, sound matching) at different levels of difficulty that contribute to the composite score.

Phonological Working Memory Composite

The phonological working memory composite is a measure of the child's ability to "code information phonologically for temporary storage in working memory" (Wagner et al., 1999, p.47), in particular the functioning of the phonological loop of working memory. The core subtests contributing to the composite measure include: memory for digits and nonword repetition. A child's ability to repeat a series of digits or nonwords of increasing length is measured.

Rapid Automatized Naming Composite

The rapid automatized naming composite is made up of two subtests of rapid serial naming: either rapid colour naming and rapid object naming tasks for the 5- and 6-year-olds, or rapid digit naming and rapid letter naming tasks for the children aged 7 years and over. The pictures on the subtests are expected to be familiar to the children and therefore measure the efficiency of retrieval of phonological information from long-term memory (Wagner et al., 1999). For example, the Rapid Colour Naming (5- and 6-year-olds) subtest measures how fast a child can name a series of coloured squares.

Rationale for Inclusion

The CTOPP provides a standardised measure of skills in three of the key areas of interest: phonological awareness, phonological working memory and phonological retrieval. The availability of composite scores in the key areas of interest enabled comparison between these areas.

The tasks on this particular test were deemed to be particularly relevant to the areas of interest. The phonological working memory tasks in the CTOPP limit the potential use of elaborate rehearsal and redintegration, and instead focus on the capacity of the phonological loop. For example, the presentation rate of digits was faster than usual (2 digits per second). The test authors suggest this "discourage[s] elaborate rehearsal strategies and stress[es] the efficiency of the phonological loop" (Wagner et al., 1999, p.9). Further the nonword repetition subtest contained nonwords that had few morphemes or lexical similarities to real words, other than they were phonotactically possible in English.

In the selection of a test to measure phonological awareness, one that forms a single construct from different tasks covering varying linguistic complexity is favourable (Anthony & Lonigan, 2004; Stahl & Murray, 1994). The phonological awareness composite, based on both elision and blending subtests, assess different levels of phonological awareness that are particularly relevant to skills for reading. For example, the elision subtest required the children to delete progressively smaller units, from syllable, to onset/rime, to phoneme and phonemes within clusters, and realize the resulting word. The blending words subtest followed a similar pattern of increasingly smaller units of speech and therefore increasing levels of linguistic complexity.

The rapid automatized naming subtests consisted of letters and digits for the children 7-years and older. Speed of rapid automatized naming of letters (Troia, Roth, & Yeni-Komshian, 1996) and digits has been significantly related to reading in children with normal hearing (Wagner et al., 1999).

The standardisation population of the CTOPP was similar to that used for the

TOWRE, facilitating comparison of these test results. The descriptions of several measures of reliability (time sampling, inter-scorer differences) and validity (content description, criterion-related and construct validity) indicate that the CTOPP is both a reliable and valid measure of phonological processing. However, when reviewing validity, consideration must be given to the population being tested and the manner in which the results are used. All the tests administered in this study were standardised on typically developing children with normal hearing. The rationale behind the decision to use a test standardised in this way was, as indicated earlier, that the participants in this study were in mainstream school settings and therefore the peer group to which the participants are compared educationally are hearing children. In addition, the reliability coefficients for eight subgroups within the normative sample were high (greater than 0.80 for all subtest and composite scores), suggesting that the CTOPP contains little bias relative to tested subgroups.

<u>Administration</u>

The CTOPP was administered using the provided original record forms and picture book. All subtests (core and supplemental), appropriate for the participant's age, were administered. An electronic stopwatch was used for the rapid automatized naming subtests. Timing began as the participant began and ceased when the participant had finished saying the last item. Errors and self-corrections were included in the overall latency measures. No participant made more than 4 errors (discontinuation rule) per form, however self-corrections were prevalent. Measurements in 0.01 seconds were obtained for each form (A and B) and then rounded to the nearest second on raw score calculation for comparison with the norms tables.

An audiotape was provided for use in administration of blending words, memory for digits, nonword repetition, blending nonwords, segmenting nonwords and phoneme reversal. The test developer's rationale for providing an audiotape for these specific sections was to improve the reliability of the test by minimising variations in examiner presentation (Wagner et al., 1999). The audiotape was not used in this study as the test recordings were in an American accent while the participants were Australian. It was considered that the participants' unfamiliarity with the American accent would reduce the validity of the results. Furthermore, children using cochlear implants may have difficulty with taped material because it provides only auditory cues. The taped material may therefore be a measure of their speech perception abilities rather than their phonological processing skills. All subtests were presented live voice. To improve reliability of the live voice presentation only one examiner administered the test to all the participants. This examiner practiced retaining the timing of item presentation to ensure consistency in presentation across participants and with the speed of the original tape provided.

Some practice items were also changed to account for cultural differences between American and Australian English, for example, on the blending words subtest instead of 'candy' being used as a practice item 'lolly' was substituted, and instead of airplane being one of the practice items on the elision subtest, ice cream was substituted. This was done because the American word 'airplane' is two syllables and the Australian word of the same meaning 'aeroplane' is three syllables. There were no test items substituted.

The participants' responses were scored according to the test instructions. Speech errors were not taken into consideration in the scoring process, except on the rapid automatized naming subtest where there was a finite set of productions, as it was considered that it could only be subjective and therefore an unreliable opinion about which errors were due to speech and which were due to an inability to perform the specific task. This issue was not addressed in the manual, as most children should have mastered most speech sounds by age 5, which is the lower age group of the standardisation. On the rapid colour naming subtest many of the participants said 'purple' for 'blue', and this was scored as correct because the shade could be reasonably judged as either blue or purple.

Subtest raw scores were converted to standard scores using the age-based normative tables in Appendix A of the CTOPP manual. The composite standard scores were of primary interest in this research as these enabled comparison of the participants' scores with the norm population as well as comparison of participants' phonological processing skills with other areas of investigation. The subtest standard scores were used to obtain composite standard scores for phonological awareness, phonological working memory and rapid automatized naming.

3.7. <u>Reporting Results to Participants</u>

Parents' of children who participated in the study were sent reports detailing the results of the assessments. The reports included recommendations for further investigation or intervention where appropriate. The researcher was available to discuss any concerns or questions the parents had regarding the results. When requests by other professionals were made for the reports or information gained from the study, parents were asked for their written consent. Parents were informed that this study was primarily concerned with group data and trends, and the publication or presentation of the results of this study would contain no identifying information of individual participants. If in the future results of one particular child are singled out for publication purposes, this child will be identified by a numerical or letter code only and names or obvious identifying information would be not be used.

3.8. Analysis of Results

The results have been divided into three sections and are reported in chapters 4 to 7 (refer to synopsis). Discussion of the results follows each study, however the studies are not independent of one another and are ordered so that each chapter builds on the findings from the preceding chapter.

In all the studies descriptive and inferential statistics are used to profile and analyse the results. The following section describes the results within each area of investigation. The results for tests are reported as standard scores if available. Standard scores are the most robust form of derived scores (Anastasi & Urbina, 1997). The use of a normalised standard score enables the comparison of participants' results with the results of children with normal hearing and with different subtests or different tests. Age and grade equivalent scores while potentially having a clinical purpose, are "psychometrically crude and do not lend themselves well to precise statistical treatment" (Anastasi & Urbina, 1997, p.55). Due to the lack of statistical rigour, age and grade equivalent scores have not been included in the analyses in this research.

3.8.1. Data Management

3.8.1.1. Data Storage and Cleansing

All data were entered into Excel spreadsheets. Data cleansing was performed. Each score was crosschecked with original file information and record forms. A total of 24 errors across 3168 cells of data were found (0.008% error in initial data entry); errors were corrected. Excel spreadsheets were copied to SPSS Base 10.0 data files, and frequency analysis was performed. This was used to check the distribution of the responses for each variable for any implausible values; none was identified.

3.8.1.2. Missing Data

Complete data across all areas of investigation were not obtained for all 47 children due to factors such as fatigue during assessment session[18] and missing file information. These issues are typical of research with children (e.g. Dettman et al., 2007; Dowell et al., 2002). This did not occur often and the total number of children tested was between 45 and 47 for all tests except a subtest of the QUIL. This was an additional test and not prioritised in the assessment battery (refer to section 3.6.1). The description and analysis of the results for each test administered are presented individually to account for the variable participant numbers.

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[18] Several participants lived in country NSW and therefore many hours from the centre. Distance from the centre rendered it difficult for many participants to return for additional testing sessions.

Chapter 4. Results and Discussion: Reading Profiles

"The person who cannot read well is simultaneously dependent on and isolated from others in significant ways and is prevented from entering into the simplest of communications with others"

(Robertson, 2000, p.23).

4.1. Profiles of Reading Outcomes

Historically, children born with a significant hearing loss achieved reading outcomes below that of their hearing peers. As established in chapters 1 and 2, the research in this area is far from comprehensive. Multiple participant variables thought to influence reading outcomes have not been carefully controlled across the research. This chapter addresses the need for better-controlled research on reading outcomes, by presenting comprehensive reading profiles of a relatively homogenous group of children with significant hearing loss using a cochlear implant. Reading is a secondary language skill that builds on oral language (Perfetti & Sandak, 2000). The selection criteria for participants in the current study stressed their auditory experience and reliance on oral language. These criteria aimed to define a group that had a strong oral focus in their language development.

Reading is a multidimensional skill. Consequently, research providing a comprehensive profile of children's reading abilities necessitates the use of multiple measures. The different facets of reading reported in this chapter include reading of common words to examine sight word reading strategies, reading nonwords to examine the participants' ability to use a phonological route, reading passage length material that adds contextual information to examine its impact on reading accuracy and to assess reading comprehension. In addition, reading efficiency is examined using timed tasks. Measures of these skill areas were obtained using three standardised tests of reading:

- The Neale Analysis of Reading Ability–Revised 3rd Edition (Neale-3) (Neale, 1999),
- The Test of Word Reading Efficiency (TOWRE) (Torgesen et al., 1999a),
- The Queensland Inventory of Language (QUIL) (Dodd et al., 1996).

The results for each test are described separately. A different number of children completed each test. The demographic and implant characteristics of the participants for each test are presented in Appendix G.

Following the presentation of the reading results, the relationship of these results with the demographic and implant characteristics of the participants is presented. The questions answered in this chapter are:

1. What are the reading (word reading and reading comprehension) outcomes for oral communicating children using a cochlear implant?

2. What demographic and implant-related factors relate to reading outcomes for oral communicating children using a cochlear implant?

4.1.1. Reading Accuracy, Comprehension and Rate for Passages

Passage reading accuracy, reading comprehension, and reading rate were measured using the Neale Analysis of Reading Ability –3rd Edition (Neale-3) (Neale, 1999). Forty five children (22 boys and 23 girls) completed the Neale-3 in this study. Descriptive statistical analysis using the percentile rank scores for reading accuracy, reading comprehension, and reading rate are summarized in Table 4-1.

Table 4-1 Summary of descriptive statistics for the reading accuracy, reading comprehension and reading rate measures in the Neale-3.

Variable	*Mean*	*Median*	*Range*	*Standard Deviation*	*Normal Range*
Accuracy Percentile Rank n = 45	30.27	16	<1 – 99	29.12	16 - 84
Comprehension Percentile Rank n = 45	21.72	8	<1 – 87	24.62	16 - 84
Rate Percentile Rank n = 45	56.25	61	<1 – 100	31.9	16 - 84

The mean group performance for reading accuracy, reading comprehension, and reading rate were all within the normal range using school grade-based norms. All three measures have large standard deviations (see Table 4-1) reflecting the wide spread of scores for the group on all three measures of reading. Performance was also analysed using median scores. For ordinal measures, the median score, rather than the group mean, may be a better measure of group performance. Using median scores, performance for reading comprehension falls below the normal range, with 26 of the 45 in the group scoring below the normal range. The median score for reading rate and reading accuracy were within the normal range. On reading rate only 6 of the 45 children scored below the normal range while half the group was below the normal range on reading accuracy. Performance on reading comprehension was poorer than reading accuracy (see Figure 4-1).

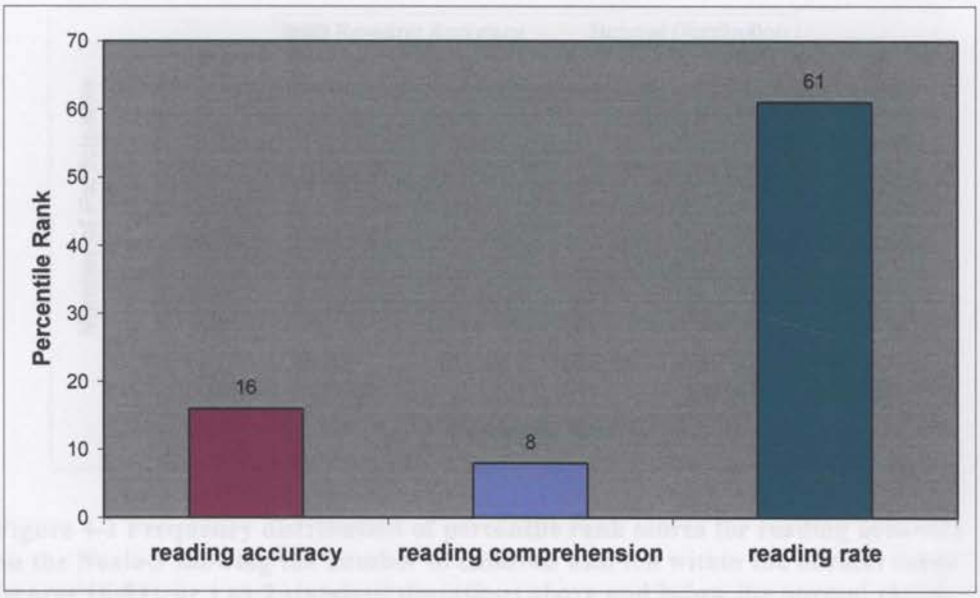

Figure 4-1 Group median scores (based on percentile rank) for reading accuracy, reading comprehension and reading rate on passage length material from the Neale-3.

Figures 4-2 to 4-4 show the frequency distributions of the percentile rank scores for reading accuracy, reading comprehension and reading rate. Visual inspection of the distributions suggests that reading accuracy and reading comprehension are negatively skewed.

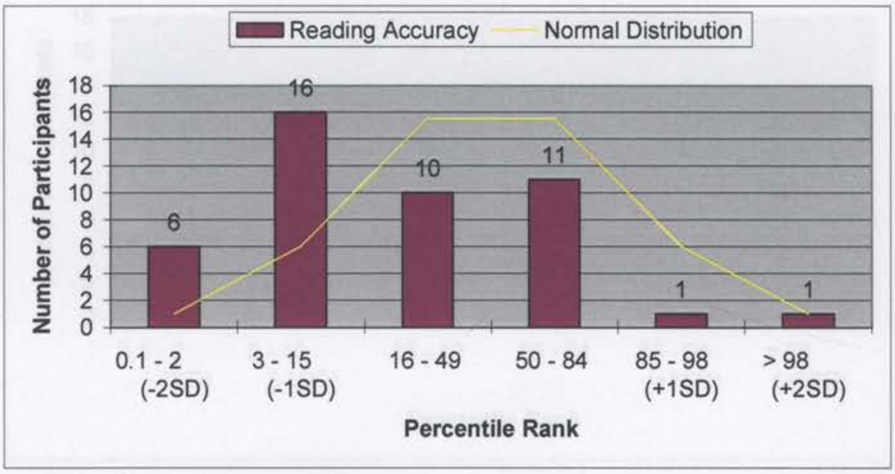

Figure 4-2 Frequency distribution of percentile rank scores for reading accuracy on the Neale-3 showing the number of children who fell within the normal range (scores 16-84), or 1 or 2 standard deviations above and below the normal range.

For reading accuracy (Figure 4-2), 46.7% of participants scored within the normal range, 2.2% of participants scored 1 standard deviation above the normal range and 2.2% scored more than 2 standard deviations above the normal range. That is, a total of 51.1 % of the participants scored within or above the normal range for reading accuracy. Of the 48.9% of participants who scored below the normal range on reading accuracy, 13.3% scored more than 2 standard deviations below the normal range, while 35.6% scored 1 standard deviation below the normal range.

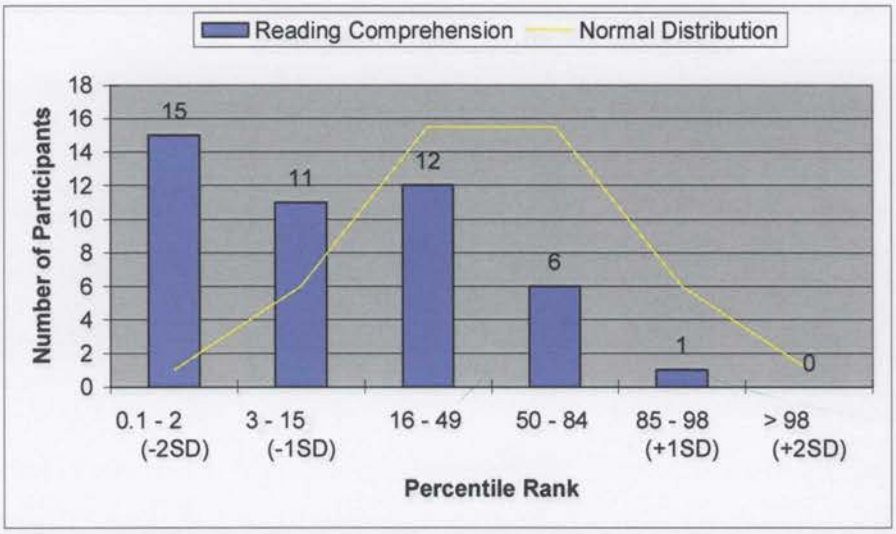

Figure 4-3 Frequency distribution of percentile rank scores for reading comprehension on the Neale-3 showing the number of children who fell within the normal range (scores 16-84), or 1 or 2 standard deviations above and below the normal range.

Results showing the frequency distribution of percentile rank scores for reading comprehension are presented in Figure 4-3. This figure shows that 40% of the participants scored within the normal range for reading comprehension and 2.2% of the participants scored 1 standard deviation above the normal range. Of the 57.8% of participants that scored below the normal range, 33.3% scored more than 2 standard deviations below the normal range, while 24.5% scored 1 standard deviation below the normal range.

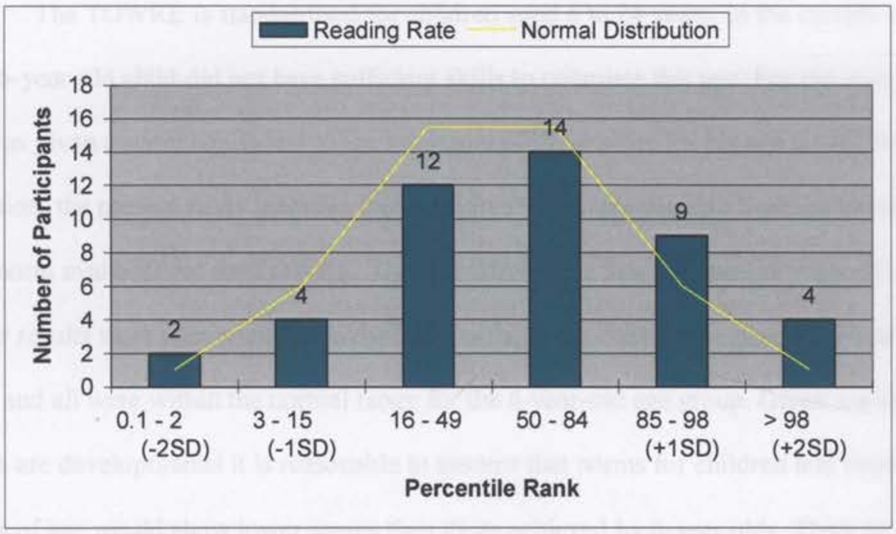

Figure 4-4 Frequency distribution of percentile rank scores for reading rate on the Neale-3 showing the number of children who fell within the normal range (scores 16-84), or 1 or 2 standard deviations above and below the normal range.

The frequency distribution of scores for reading rate is presented in Figure 4-4. This figure shows that the participants reading rate was commensurate with the normal distribution for children with normal hearing. Only 13.3% of the participants scored below the normal range for reading rate, while 57.8 % of the participants scored within the normal range, 20% scored 1 standard deviation above the normal range and 8.9% scored more than 2 standard deviations above the normal range.

4.1.2. Word Reading Efficiency: Sight Word Reading and Phonemic Decoding Efficiency

The reading accuracy, comprehension, and reading rate results on the Neale-3 depicted in Figures 4-2, 4-3 and 4-4, are based on passage length material. The Test of Word Reading Efficiency (TOWRE) tests the accuracy and fluency of reading a list of familiar words (sight word reading efficiency) and nonwords (phonemic decoding efficiency).

The TOWRE is standardised for children aged 6 to 24 years. In the current study one 6-year-old child did not have sufficient skills to complete this test. For the analysis he was given a score equivalent to the minimum positive score for his age group. In addition, the present study included three children who were younger than the lowest age norm available for the TOWRE. These children were 5;6, 5;6 and 5;9 years old. Their results were converted to standard scores using the conversion table for 6-year-olds and all were within the normal range for the 6-year-old age group. Given reading skills are developmental it is reasonable to assume that norms for children less than 6 years of age would show lower scores than those achieved by 6-year olds. There is, therefore, a greater risk in labeling age appropriate performance as below age level by comparing them to norms of an older age group. Given this did not occur, the results for the three participants were included. However, the impact of this was assessed by conducting two analyses; one with the younger children included (n = 46) and one without the younger children included (n = 43), reported in Table 4-2. There was a difference of 0.22 years in the mean age at assessment for the groups. Overall, the demographic and implant characteristics for the two groups were very similar to each other (see Appendix G) and to the overall participant group of 47.

Table 4-2 reports the word reading efficiency results with and without inclusion of the younger children and the results for mean, range and standard deviation scores are similar. The younger children were therefore included in subsequent analyses, to provide information on the larger participant group. All following analyses and the discussion regarding the results on the TOWRE also refer to the 46 participants.

Table 4-2 Results for sight word reading and phonemic decoding from the TOWRE for the group excluding 3 children under 6 years (n=43) and for the whole group (n=46).

Variable	*Mean*	*Median*	*Range*	*Standard Deviation*	*Normal Range*
Sight Word Reading Efficiency SS					
n = 46	96.76	96.00	71 – 140	13.97	85 – 115
n = 43	96.46	95.00	71 – 140	14.33	
Phonemic Decoding Efficiency SS					
n = 46	94.26	95.00	59 – 132	17.75	85 - 115
n = 43	93.67	94.00	59 – 132	18.17	

The mean standard scores for the sight word reading efficiency and phonemic decoding efficiency were both within the normal range (see Table 4-2). The standard deviations were both similar to the normal distribution standard deviation (SD = 15). Figures 4-5 and 4-6 present the frequency distribution of scores for both sight word reading efficiency and phonemic decoding efficiency. The Q-Q plots (see Appendix I) indicate that both distributions are normally distributed. However, the phonemic decoding efficiency scores were more negatively skewed than sight word reading efficiency and the normal distribution.

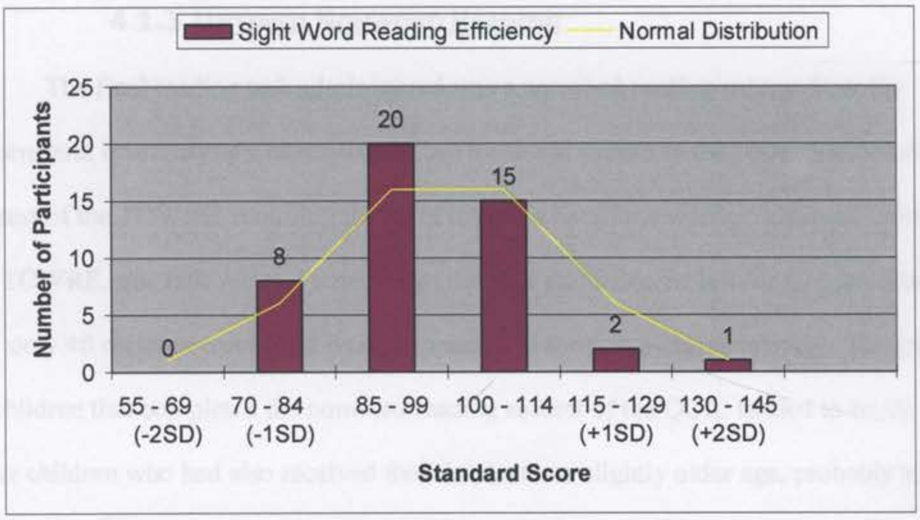

Figure 4-5 Frequency distribution of standard scores for sight word reading efficiency on the TOWRE showing the number of children who fell within the normal range (scores 85 - 115), or 1 or 2 standard deviations above and below the normal range.

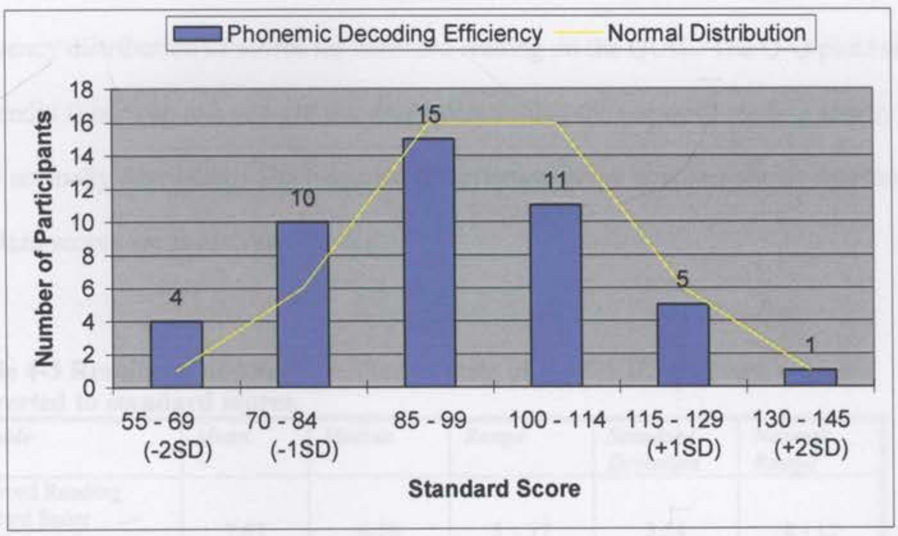

Figure 4-6 Frequency distribution of standard scores for phonemic decoding efficiency on the TOWRE showing the number of children who fell within the normal range (scores 85 - 115), or 1 or 2 standard deviations above and below the normal range.

4.1.3. UNTIMED NONWORD READING

The final reading task administered was a nonword reading subtest from the Queensland Inventory of Literacy (QUIL). This test is similar to the phonemic decoding subtest of the TOWRE, requiring the child to read a list of nonwords. However, unlike the TOWRE, this task was not timed. This test was administered last for all participants and only 40 children completed it (see Appendix G for group characteristics). The group of children that completed the nonword reading subtest of the QUIL tended to be the older children who had also received their implant at a slightly older age, probably as these older children were less likely to exhibit fatigue on the day of assessment.

The results for the nonword reading subtest of the QUIL are presented in Table 4-3. The mean nonword reading standard score was 7.07 and median was 6.50. Both these values were below the normal range (+/- 1 SD = 8 – 12). Figure 4-7 presents the frequency distribution of scores for nonword reading on the QUIL. The Q-Q plot (see Appendix I) is close to a straight line and indicates that the nonword reading scores were normally distributed. The frequency distribution graph however shows that the standard scores are negatively skewed.

Table 4-3 Results on nonword reading subtest of the QUIL with raw scores converted to standard scores.

Variable	*Mean*	*Median*	*Range*	*Standard Deviation*	*Normal Range*
Nonword Reading Standard Score n = 40	7.07	6.50	3 – 17	3.54	8 - 12

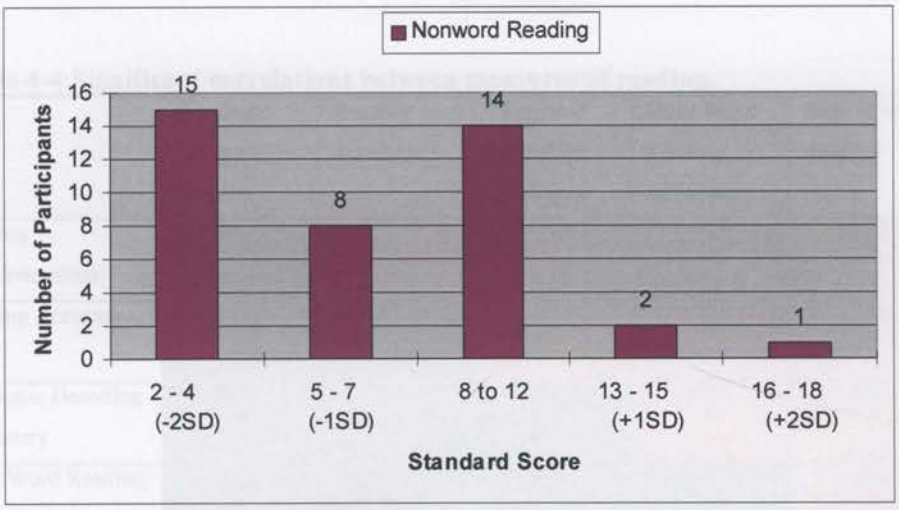

Figure 4-7 Frequency distribution of standard scores for nonword reading on the QUIL showing the number of children who fell within the normal range (scores 8 - 12), or 1 or 2 standard deviations above and below the normal range.

4.1.4. RELATIONSHIPS BETWEEN MEASURES OF READING

Strong significant correlations between measures of reading were anticipated and found. All combinations of reading measures were strongly correlated (see Table 4-4). The correlation between reading accuracy and reading comprehension was particularly strong (p = .894, n = 45), as were the correlations between nonword reading and reading accuracy (p = .858, n = 39) and phonemic decoding efficiency (p = .820, n = 40).

Table 4-4 Significant correlations between measures of reading.

	Reading Compre-hension	*Reading Accuracy*	*Phonemic Decoding Efficiency*	*Sight Word Reading Efficiency*	*Non-word Reading*
Reading Comprehension		.894	.740	.770	.774
Reading Accuracy			.757	.716	.858
Phonemic Decoding Efficiency				.758	.820
Sight Word Reading Efficiency					.610
Non-word Reading					

*[*Red shaded boxes indicate variables that have a significant ($p = 0.01$) strong correlation.]*

4.2. Relationships of Reading with Demographic and Implant Related Variables

The data were analysed to determine whether contributory variables cited in the literature were associated with the reading outcomes obtained. Possible associations between reading measures and demographic and implant-related factors were investigated using correlation analyses. Two correlation analyses were run. The first consisted of a Pearson r correlation analysis for reading outcomes reported as interval data. This included the standard score results for sight word reading, phonemic decoding, and nonword reading. A second analysis, a Spearman rho correlation used reading outcomes reported as ordinal data: this included percentile rank results of the Neale-3 for reading accuracy, comprehension and rate.

The relationships between reading, and demographic and implant-related variables are presented in Table 4-5. The correlation coefficients used the demographic variables of mother's education level and number of children in the family, and the audiological variables of age at assessment, age at hearing aid (HA) fitting, age at cochlear implantation and number of years using a cochlear implant. A significance level of 0.01 was adopted. A description of the strength of the significant relationship was based on the correlation coefficient, with values 0.6 or higher labeled strong relationships and significant correlations below 0.6 were labeled moderate relationship.

Table 4-5 Relationships of reading and demographic and implant-related variables.

	Age at Testing	*Age at CI fitted*	*Age HA Fitted*	*Years Using CI*	*Mothers Education*	*No. of children in family*
Reading Comprehension	-.133	.070	-.125	-.182	.261	-.417*
Reading Accuracy	-.142	.066	-.167	-.175	.242	-.525*
Sight Word Reading Efficiency	-.352	.001	-.081	-.370	.283	-.393*
Phonemic Decoding Efficiency	-.146	.127	.016	-.259	.350	-.429*
Nonword Reading (untimed)	-.176	.140	-.099	-.288	.280	-.277

*[*Blue shaded boxes indicate variables that have a significant (p = 0.01) moderate correlation.]*

All measures of reading outcomes showed no significant relationship with any of the audiological variables or with mother's education level. However all measures of reading, with the exception of untimed nonword reading from the QUIL, showed a moderate significant negative correlation with number of children in the family (see Table 4-5). The negative correlation indicates that as the number of siblings increases, reading outcomes get poorer. Figure 4-8 presents the scatter plot graph of this significant relationship and shows that this negative trend is present when there are three or more siblings. Participants with one or two siblings scored across the full range of reading comprehension scores, while scores of participants with three or more siblings were all in the low range.

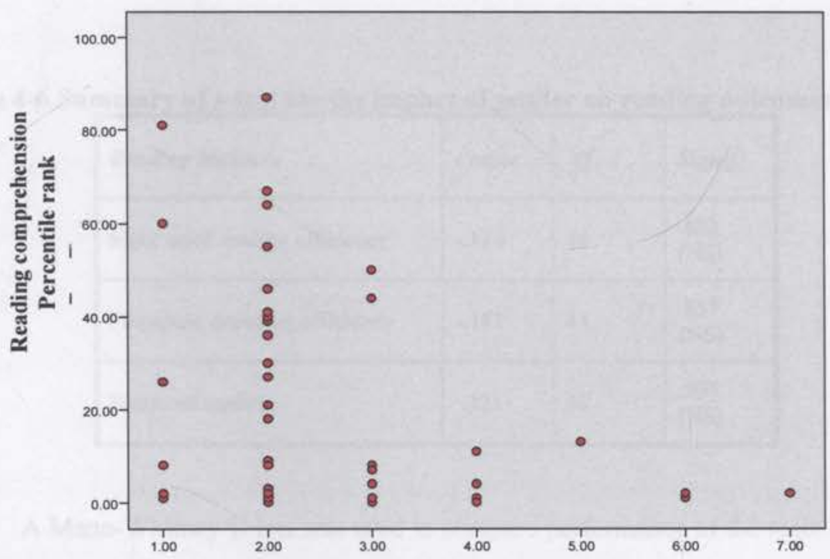

Figure 4-8 Reading comprehension outcomes for participants with differing number of siblings.

4.3. <u>Gender Differences in Reading Outcomes</u>

Results for the male and female children were compared on each of the measures of reading. Those measures that used standard scores (sight word reading efficiency, phonemic decoding efficiency and nonword reading) and therefore interval data were analysed using independent *t* tests. An equal number of boys and girls completed each test: word reading efficiency tests (boys = 23, girls = 23), nonword reading (boys = 20, girls = 20). Levene's Test of Equality of Variance was not significant for any of the variables and therefore equality of variance was assumed. The results show no significant difference between the male and female children for any of the three areas of word reading (sight word reading efficiency, phonemic decoding efficiency, and nonword reading) (refer to Table 4-6).

Table 4-6 Summary of *t*–test for the impact of gender on reading outcomes.

Reading Measure	*t value*	*df*	*Signif.*
Sight word reading efficiency	-.136	44	.893 (NS)
Phonemic decoding efficiency	-.181	44	.857 (NS)
Nonword reading	.121	38	.905 (NS)

A Mann-Whitney U test was used to compare performance of the male and female children on the other reading measures; that is, reading accuracy and reading comprehension, which were in percentile ranks. The analysis showed no significant difference between the groups for reading accuracy (U = 251.50, z = -.034, p = .973) and for reading comprehension (U = 240.50, z = -.285, p = .776).

These analyses revealed no significant gender differences in reading outcomes. Consequently, all subsequent analyses did not include gender as a variable.

4.4. Discussion: Chapter 4

4.4.1. Reading Profiles

This study aimed to profile the word reading and reading comprehension outcomes for children using a cochlear implant and oral communication. The results show that the group performed within the normal range for typically developing children on word reading for both sight word reading efficiency and phonemic decoding efficiency. However, on reading comprehension the group result was below the normal range. This difference in outcomes for word reading versus reading comprehension confirms that these skills are not always related and need to be assessed separately. Perfetti (1995, p.108) claimed that "the hallmark of skilled readers is fast, context free word identification and rich context dependent text understanding." The results suggest that while the participants have achieved their first step in becoming skilled readers, they are not performing at the same level as their typically developing peers in understanding what they read.

On the word reading efficiency tests, 83% of participants achieved results within or above the normal range for their age for sight word reading efficiency, while only 69.5% performed at this level for phonemic decoding efficiency. These results indicate that the majority of participants were able to read the printed word in a time efficient manner. However, sight word reading efficiency was significantly better than phonemic decoding efficiency. This difference suggests that they have more difficulty utilising a phonemic decoding strategy than an orthographic (sight word) strategy to read. Such a finding is not unexpected. Past research on children with a significant hearing loss has centered on whether they are even able to utilize a phonological route to word reading at all (see Musselman, 2000). What is remarkable is that 69.5% of participants in this study were able to use a phonological route as efficiently as their normally hearing peers.

The current study used two different nonword reading tests to measure phonemic decoding skills. One test was timed and the other untimed. The timed measure (from the TOWRE) focuses on the robustness of a child's use of the phonological route in reading, by determining the number of nonwords a child can decode in a set time. Contrary to expectations, the results show that performance on the timed test was better than on the untimed nonword test (from the QUIL). Only 30.5% of the children scored below the normal range on the timed nonword reading task, whereas 50% of the children who did the untimed task scored below the normal range. Factors such as the skills required to succeed on each test, and methodological issues such as the number of participants to complete each test and the order of the tests were investigated.

While both tests assessed nonword reading, the use of timing on the TOWRE may have produced better outcomes by limiting the number of two- and three-syllable words read. Longer words require more details to be specified and temporarily stored in phonological working memory during grapheme- phoneme conversion and are therefore presumably harder to process. Although both tests have two- and three- syllable words, there are 29 monosyllabic words in the timed test (TOWRE) and only 8 monosyllabic words in the untimed test (QUIL) before the bisyllabic words are presented. Performance on the TOWRE is based on the number of words read correctly in 45 seconds. The time limit resulted in many participants not attempting the bisyllabic and polysyllabic words before the test was discontinued at the end of the time allowed. The untimed test format of the QUIL however, meant that the children read more bisyllabic or polysyllabic words.

In addition to task differences, the tests differed in their standardisation populations. The TOWRE standardisation used a large population of American children while the QUIL was standardised on a smaller population of Australian children. The more rigorous standardisation procedures used in the development of the TOWRE and the similarity of its standardisation population to those of the other tests used in the study test battery lead to this test being selected in the battery used for this study. The QUIL was included because of its Australian standardisation but was always administered as the final test. For this reason fewer children completed the QUIL. The smaller number of participants, difference in standardisation population or because the QUIL was always presented last when the children may have been affected by fatigue, may have contributed to the poorer outcomes on this task. However, the difference in results between the two tests suggests the need to explore the strength of the participants' phonological route. This issue is further explored in chapters 6 and 7 of this thesis.

The children in this study were taught to read in a mainstream education system that favoured a whole language approach (deLemos, 2002). The whole-language approach to reading promotes utilization of a top-down strategy to read, with reduced focus on bottom-up skills such as phonics. In the current study, the participants' reading accuracy on passage length material was poorer than for single words. In passage reading, the contextual information appears to have imposed additional processing on the child rather than assisting in the decoding process.

Why do these children as a group have more difficulty with passage word reading that provides the opportunity for top-down as well as bottom-up processing strategies to read words, than lists of words? Word reading of passages is a complex task that requires integration of material. That is, the children have to read the words aloud and then store the information for comprehension. However, the difference may also reflect the nature of the stimulus words used in each of the tests. In the TOWRE, the first 35 sight words on the reading efficiency test are monosyllabic words, followed by simple disyllabic words such as 'better' and 'winter' before the stimulus words become less familiar and polysyllabic. In the Neale-3 passage word reading task (reading accuracy), even on Level 2 passages (the second stimulus passage) there are polysyllabic words such as 'bicycles', 'television', 'Saturday' and 'electric'. Given this analysis of the test content, the results suggest that the participants in the current study have greater difficulty reading longer words, and that context does not overcome the effects of word length in passage reading. That is, the participants depend on bottom-up processes (sight word reading and/or phonemic decoding). Sight words are familiar and can be read quickly, while unfamiliar words require phonemic decoding. The polysyllabic words in the reading passages may be common in a spoken form (e.g. 'bicycle'), but may not be established as sight words (as evidenced by the low accuracy scores) and require phonemic decoding. Nonetheless, for word reading accuracy on passage reading more than half of the participants scored within or above the normal range. However, reading comprehension was significantly poorer than reading accuracy for passages. This result suggests that on passage reading, some participants could read the words but could not gain meaning from words they read.

Why, if the code has been deciphered and the written words encoded into the correct spoken form can the children not achieve reading comprehension outcomes equivalent to reading accuracy outcomes? The result suggests that other skills, apart from word reading, are contributing to reading comprehension. Language comprehension is typically cited as a pre-requisite for reading comprehension (Catts et al., 2006; Catts & Kamhi, 2005; Hoover & Gough, 1990; Kyle & Harris, 2006). The participants in the current study have age/grade-appropriate word reading skills, but may not have sufficient world knowledge or broader language skills to enable them to understand passage length material, or to answer a variety of different question types including open-ended questions. The questions on the reading comprehension tasks required the children to infer information from the text. Higher-level language and shared knowledge of the text topics is needed to achieve success on the reading comprehension task.

While the reading comprehension results obtained in the current study indicate that the participants are performing at a lower level than age/grade-equivalent typically developing children, their results are better than some previous studies of reading comprehension in children using a cochlear implant (Spencer et al., 1999; Vermeulen et al., 2007). However, the reading comprehension results are not as good as the studies by Geers (2003) and Fagan et al. (2007). These American studies reported mean reading scores of children who used a cochlear implant were within the normal range. Direct comparisons of the findings of this study with the studies from America are somewhat hindered by the use of different assessment tools, their use of a combined reading scores, and the complexity of the reading comprehension task. The standardised reading scores reported in both the Geers and Fagan et al studies were a composite of both word reading and reading comprehension subtests. If, as was found in the present investigation, the word reading scores were significantly better than the reading comprehension scores, then the overall reading scores will consequently suggest better reading scores than what might be the case if reading comprehension scores were presented in isolation from word reading. In addition, the task from which the reading comprehension score was derived in the current study reflects usual classroom reading tasks and required the participants to answer open-set questions relating to passages read aloud. Such a task draws largely on language skills and is more complex than the single sentence reading comprehension task with a closed-set picture selection choice task that was used in both the Geers and Fagan et al studies. The closed-set selection task used in both the Geers and Fagan et al studies may be more of a reflection of the children's ability to eliminate options than their comprehension of text.

The few studies that have investigated aspects of word reading in children using a cochlear implant (see section 1.2.4.1) have also been administered somewhat differently to the current study. The current study documented both the sight word reading efficiency and phonemic decoding efficiency results of the children independently, as separate aspects of reading. Whereas Fagan et al. (2007) included sight word reading as a component of the overall reading measure that included reading comprehension and reported the results of a nonword and rare word reading task separately. Fagan et al reported that the nonword/rare word reading mean standard score of a small group of children using a cochlear implant was 101. If an overall picture or trend was to be identified, the current study of the reading skills of oral children using a cochlear implant builds on the results of Fagan et al and indicates that the majority of children using a cochlear implant and oral communication have word reading skills comparable to children with normal hearing.

Both the accuracy and speed of word reading are important factors in enabling cognitive resources to be used for comprehending written text (Torgesen et al., 1999a). In the current study, reading rate based on the time it took to read a passage was measured, and 87% of the participants scored within the normal range. This result was in part, a consequence of the structure of the test. The early passages of the Neale-3 reading comprehension test are shorter and designed for early school grade reading ability. Many of the older children in the current study reached the test discontinuation level on these early passages. The typically high reading rate scores in conjunction with poorer reading accuracy and reading comprehension scores suggested that reading rate reflected the length of the passages read rather than the participants' reading efficiency. As a consequence, the reading rate scores were omitted from the analyses of relationships between skill areas presented in chapter 7.

According to the simple view of reading, reading comprehension is primarily comprised of word reading and language comprehension skills (Catts et al., 2006; deLemos, 2002; Konold, Juel, McKinnon, & Deffes, 2003). This suggests that the children in this study, who have good word reading outcomes in the presence of poor reading comprehension, will also have poor language skills. The language skills of the participants are explored in chapter 5, and the relationship between reading comprehension and spoken language comprehension is explored in chapter 7. The next section discusses the findings on the relationship of contributory variables to reading outcomes.

4.4.2. IMPACT OF DEMOGRAPHIC AND IMPLANT-RELATED VARIABLES TO READING OUTCOMES

The results indicated that the majority of the contributory variables investigated in the current study had little relationship to the participants' reading outcomes. Only one variable, the number of children in a family, was significantly related to reading outcomes. The participants with more siblings had poorer reading outcomes.

In the study by Geers (2003) family size was not found related to reading outcome. The difference in results may be due to the differences in communication approaches of the participants. In the Geers study families used a variety of communication approaches with varying degree of emphasis on audition. The varying reliance on audition and emphasis on parents as primary educator may account for lack of effect of the family size in the Geers study. It is possible that larger households may produce more ambient noise and may leave less time for one-to-one interaction. These factors will have more impact on children reliant on audition than children who have developed language via a communication approach that incorporates sign language.

A strength of this research is that all the participants were implanted through one cochlear implant centre and received AVT while attending weekly sessions in preparation for and following cochlear implantation. Auditory-verbal practice is strongly dependent on parent participation in therapy and their assumption of the role of primary educator and advocate for their child. The AV approach places emphasis on developing language skills through listening, encouragement of book sharing and the guidance and coaching of parents in language stimulation techniques. It has been said that the AV approach promotes emergent literacy practices and the development of phonological awareness (Kaderavek & Pakulski, 2007; Robertson, 2000). The finding that the number of children in the family had a negative impact on reading outcomes of the children in this research provides some indication that a parent's ability to dedicate time and adhere to the principles of auditory-verbal practice may have a significant impact on the child's outcomes. Systematically investigating factors that might influence intervention (e.g., clinician experience, therapy techniques, session content, parental commitment to and knowledge of AVT, parent's application of auditory-verbal practice into everyday experiences, signal-to-noise ratio in the home and educational environments) and/or promoting emergent literacy practices (e.g., maternal responsiveness, availability of books, shared reading time) would be interesting factors to consider in future research.

The education level of the mother was not strongly associated with reading performance as in other studies. In children with normal hearing, socio-economic status is reported that to be a significant factor affecting language and literacy outcomes and is related to factors such as the linguistic environment, availability of books, and shared reading time (Snowling & Hayiou-Thomas, 2006). In children with normal hearing, mothers with a higher level of education have been found to be more responsive to their child's communicative acts and a mother's educational level has been linked to language outcomes (Yoder & Warren, 2001). Dearing, Kreider, Simpkins and Weiss (2006) found that there was a gap between the reading levels of children with more and less educated mothers, however they reported that "this gap was nonexistent if family involvement levels [in the school] were high" (p.661). All participant families in the current study participated in AVT. In Australia, families with a child who has a hearing loss are given free access to educational programs such as AVT. This intervention provides guidance to parents on language models, integration of listening, language, and speech goals into everyday activities and promoted book sharing, thereby increasing the language input and communicative responsiveness of mothers across educational levels. However it should be noted that there is a very small standard deviation in the number of years of education of the participants' mothers with the mean years of education suggesting tertiary education. Therefore it is also possible that the absence of a relationship between reading and mother's education level is due to the high level of education of most of the mothers of participants in the present study.

The two studies in the literature that looked at age of implantation and reading outcomes found differing results. Connor and Zwolan (2004) found younger age of implantation was positively associated with reading, while Geers (2003) found that younger age of implantation was not significantly related to reading (Geers, 2003). The fact that a relationship between age of implantation or hearing aid fitting and reading outcomes was not found in the current study is probably because of the small range in age at time of implantation, or because age of implantation does not impact on children who are predominately implanted between 14 months and 3 years. Most of the children in this study were implanted at a relatively young age: over half under the age of 3 years and a quarter under the age of 2 years. There are currently no studies that have compared the reading outcomes of children implanted prior to and after 12 months of age. However given that newborn hearing screening is routinely conducted in NSW, Australia and a number of other countries, implantation of children with profound hearing loss under 12 months of age is likely to become more common. Dettman, Pinder, Briggs, Dowell and Leight (2007) recently reported that the rate of language development of children implanted under 12 months of age was comparable to children with normal hearing and better than that of children implanted between 1 and 2 years of age. Yoshinaga-Itano, Sedey, Coulter and Mehl (1998) found that children whose hearing loss was identified prior to 6 months of age had significantly better language skills to those identified after 6 months, but that there was no significant difference in the language skills of children whose hearing loss was identified after 6 months of age. Both these studies only looked at language outcomes and not reading outcomes. Future research that explores the reading outcomes of children identified by newborn hearing screening and fitted with appropriate hearing devices under, 6 months or 12 months of age is warranted.

4.5. Chapter 4 Summary

This study profiled a broad range of reading outcomes for oral communicating children who use a cochlear implant. The differing abilities of the children across the different reading tasks highlight the importance of using a battery of tests to establish reading level. The results also highlight the need for word reading efficiency skills of children using a cochlear implant to be tested. It was found that the children in this study typically had good word reading efficiency skills when compared with children who have normal hearing. However, the children experienced more difficulty accurately reading and comprehending passage length material. Their reading comprehension outcomes as a group were below the normal range. Within the group there was wide variation in reading skill level and remarkably on the phonemic decoding efficiency task 13% of participants (6 of the 46) scored above the normal range for their age. While such a result is impressive the results also showed that 30% scored below the normal range.

The policy paper "Literacy for All: The Challenge for Australian Schools" (1998) stated that "High levels of literacy for all Australians are required so that each individual can deal confidently with the broadening scope and multiple uses of literacy in all spheres of society". It is the broadening scope in the use of written material in today's society that may widen the gap between children with a significant hearing loss and their hearing peers if they are unable to attain adequate reading comprehension outcomes. Consider the social implications for young people unable to effectively communicate via email, extract information from the internet, and understand the sports report or front page story in the newspaper. While the present study indicates that more children who use a cochlear implant are achieving age appropriate reading skills than reported for children with profound hearing loss in the past, the persistence of low reading comprehension skills requires further investigation. What accounts for the low reading comprehension results? It does not appear to be solely an issue of word reading, although this certainly has a role. In this study targeted demographic and implant related factors, other than number of children in the family, were not related to the reading scores. The wide variation in the reading scores of the children in this study therefore remains to be explained. The following chapters will explore the language and speech production skills of these children and the relationship of these skills to their reading outcomes.

Chapter 5. Results and Discussion: Speech Perception, Speech Production, and Language Profiles

"As the ability to read and write can be thought of as parasitic upon language, the corollary of this assumption is that oral language skills, both expressive and receptive, are important for reading and spelling."

(Kyle & Harris, 2006, p.273)

5.1. Profiles of Speech Perception, Language and Speech Production Outcomes

Mastering written and spoken language is challenging for a child using a cochlear implant. Chapter 4 reported on one aspect of the written language outcomes achieved by the participants by profiling their reading abilities. The results showed below normal range performance on reading comprehension, with normal range performance on word level reading. In chapter 1 literature was reviewed that highlighted that the speech perception, language and speech production skills of children using a cochlear implant have typically been found to be below the skills of children with normal hearing. However, it was also noted that great variability in skills within a group have been found with numerous factors reported to influence outcomes. In this study a number of factors known to influence outcomes were controlled. In particular the participants were all oral communicators and had participated in auditory-verbal therapy. This chapter answers the questions: what are the speech perception, expressive and receptive language and speech production skills of oral communicating children using a cochlear implant? This chapter presents results that profile the participants' outcomes in each of these areas. These data provide a basis for exploring the development of speech-language connections and language- reading connections explicit in the cascade of benefits proposed by Summerfield and Marshall (1999) as linked to cochlear implantation.

5.2. Results for Speech Perception Outcomes

The participants' speech perception skills were assessed using two open-set speech tests: a sentence test, the Bench-Kowal-Bamford (BKB) sentence test (Bench et al., 1987), and an open-set word recognition test, the Consonant-Nucleus-Consonant (CNC) words (Peterson & Lehiste, 1962) (described in chapter 3). All 47 of the children in the study completed both these tests.

Table 5-1 presents results on the speech perception tests. The mean percent correct for words in sentences (BKB test) was 88.43% while the median score was 90%. On the word identification test (CNC word test) the mean percent correct score for was 65.72% that was close to the median correct score of 68.00%.

Table 5-1 Results showing percent correct on tests of speech perception for words in sentence context (BKB) and words in isolation (CNC) for all participants.

Variable	*Mean*	*Median*	*Range*	*Standard Deviation*
BKB words: (n = 47)	88.43	90.00	38 – 100	11.16
CNC words: (n = 47)	65.72	68.00	37 – 95	15.23

The distribution of scores for correct identification of words in a sentence context and words in isolation are presented in Figures 5-1 and 5-2. The words in sentence context have a positively skewed distribution with 23 of the 47 participants scoring in the top decile, suggesting a ceiling effect on this task. The score distribution for the CNC word test is flat with few children scoring in the top decile and 38 of the 47 children scoring between 50% and 90%.

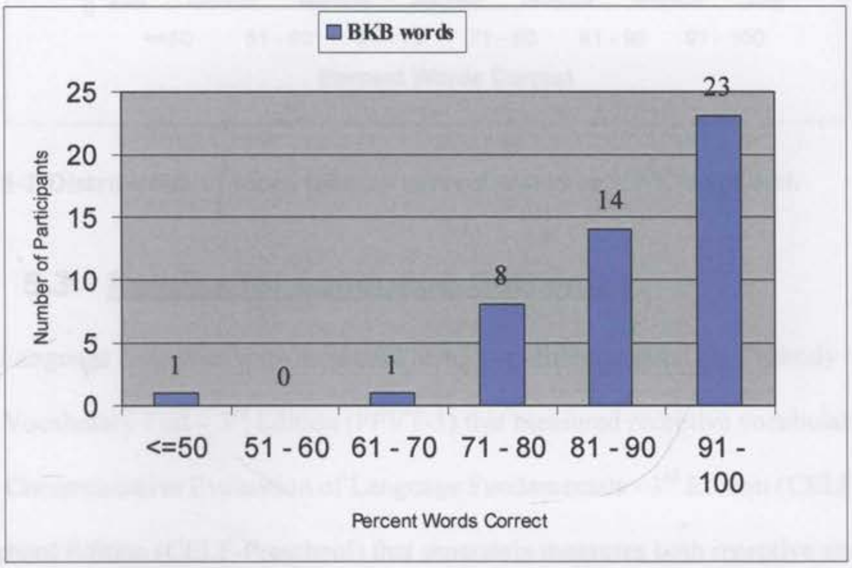

Figure 5-1 Distribution of mean percent correct scores on BKB sentence test.

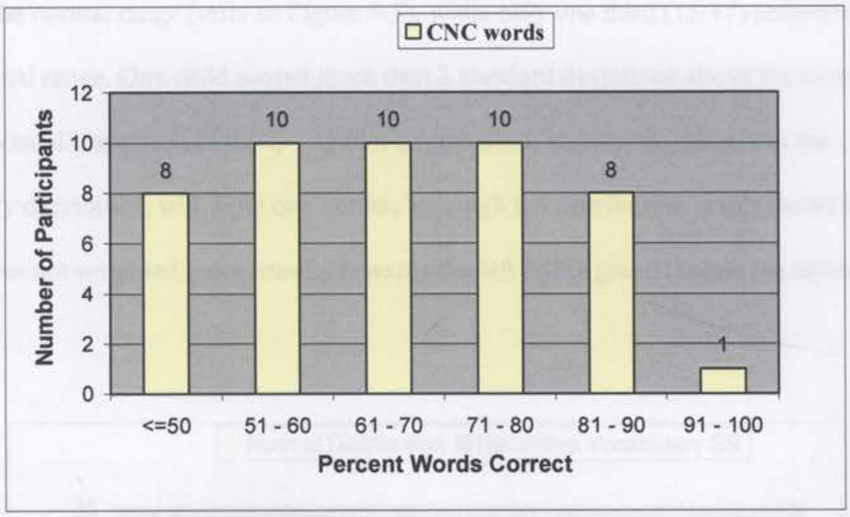

Figure 5-2 Distribution of mean percent correct scores on CNC word test.

5.3. Results for Language Outcomes

Language outcomes were measured using two different tests: the Peabody Picture Vocabulary Test – 3rd Edition (PPVT-3) that measured receptive vocabulary, and the Comprehensive Evaluation of Language Fundamentals - 3rd Edition (CELF-3) or Preschool Edition (CELF-Preschool) that separately measures both receptive and expressive language. Descriptive statistical analyses were performed on the standard scores for receptive vocabulary, receptive language and expressive language. The outcomes for each test are described individually.

5.3.1. Outcomes for Receptive Vocabulary

All 47 participants completed the receptive vocabulary test (PPVT-3). The mean standard score for the group of 77.21 was slightly higher than the median standard score of 76. Both of the mean and median standard scores were more than 1 standard deviation below the normal range (+/- 1 SD = 85 – 115). The distribution of scores for the participants in the group showed that two thirds of the participants (31/47) scored below the normal range (refer to Figure 5-3), while only one third (15/47) scored within the normal range. One child scored more than 2 standard deviations above the normal range. Visual inspection of the Q – Q Plot (Appendix I) shows that the scores are normally distributed, with only one outlier, although the distribution graph shows that the scores are weighted more heavily towards the left of the graph (below the normal range).

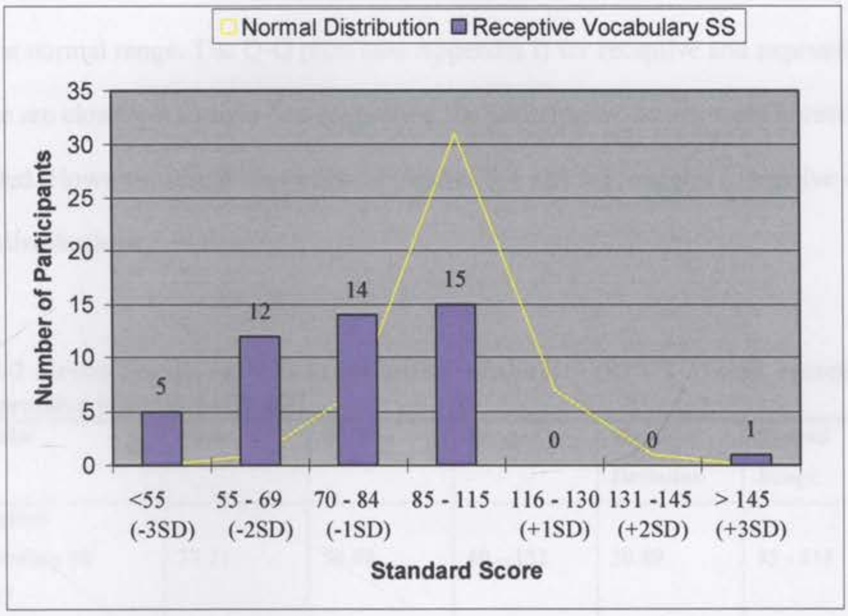

Figure 5-3 Frequency distribution of standard scores for receptive vocabulary measured using the PPVT-3 showing the number of children who fell within the normal range (scores 85 - 115), or 1, 2 and 3 standard deviations above and below the normal range.

5.3.2. <u>OUTCOMES FOR RECEPTIVE AND EXPRESSIVE LANGUAGE:</u>

The CELF-3 and CELF-Preschool provide composite scores for both expressive and receptive language. The composite scores were calculated from a range of tasks addressing aspects of each area. This analysis was based on the composite score and does not report individual tasks. Forty-six of the 47 children participating in the research were assessed on the CELF-3 or CELF-Preschool.

Table 5-2 presents results for receptive language and expressive language composite scores for the whole group. The results show that the group mean and median scores for both expressive language and receptive language were below the normal range. Performance on receptive language was better than expressive language with 48% (22/46) of the participants scoring at or above the normal range for receptive language while for expressive language only 35% (16/46) of participants scored at or above the normal range. The Q-Q plots (see Appendix I) for receptive and expressive language are close to a straight line suggesting the participants' scores were normally distributed. However, visual inspection of Figures 5-4 and 5-5, suggest a negative skew in both distributions.

Table 5-2 Group results on tests of receptive vocabulary (PPVT-3) and, receptive and expressive language (CELF)

Variable	*Mean*	*Median*	*Range*	*Standard Deviation*	*Normal Range*
Receptive Vocabulary SS n = 47	77.21	76.00	40 – 152	20.69	85 - 115
Receptive Language SS n = 46	83.15	83.50	50 – 122	19.27	85 - 115
Expressive Language SS n = 46	79.61	80.00	40 –131	21.39	85 - 115

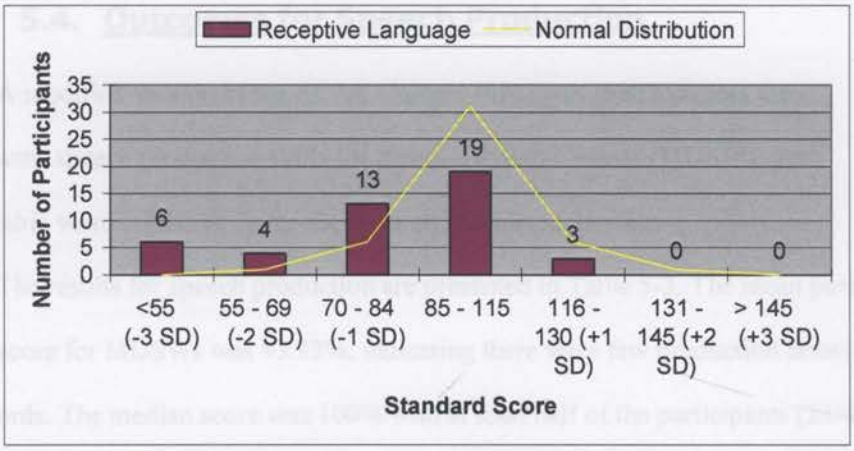

Figure 5-4 Frequency distribution of standard scores for receptive language measured using the CELF showing the number of children who fell within the normal range (scores 85 - 115), or 1, 2 and 3 standard deviations above and below the normal range.

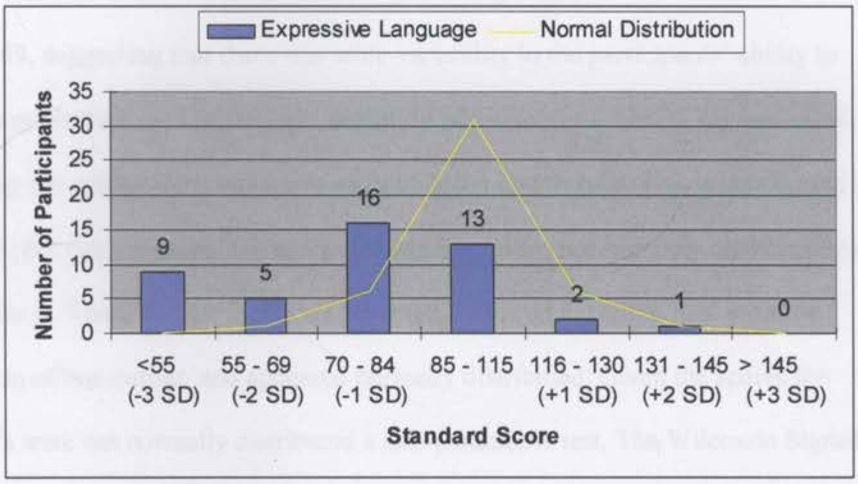

Figure 5-5 Frequency distribution of standard scores for expressive language measured using the CELF showing the number of children who fell within the normal range (scores 85 - 115), or 1, 2 and 3 standard deviations above and below the normal range.

5.4. Outcomes for Speech Production

A modified version of the ACAP (James, 1995) was used to assess the participants' speech production skills for mono- disyllabic words (MDSWs) and polysyllabic words (PSWs). Forty-six children completed this test.

The results for speech production are presented in Table 5-3. The mean percent correct score for MDSWs was 93.92%, indicating there were few production errors on short words. The median score was 100% with at least half of the participants (24/46) producing all the target words accurately (see Figure 5-6). Production of PSWs was, by comparison, poor. The mean percent words correct score for PSWs was 76.80% and the median score was 83%. These values could be said to be below the performance level expected of 6-year-old children with normal hearing[19]. The standard deviation for PSWs was 20.69, suggesting that there was wide variability in the participants' ability to produce polysyllables. The standard deviation of the scores for MDSWs was small, reflecting the ceiling performance of most children on this task. This was reflected in the Q-Q plot that suggested the scores for MDSWs were not normally distributed (see Appendix I). The Q-Q plot for PSWs however, followed a straight line, with the exception of one outlier, and appeared normally distributed. Given the scores for MDSWs were not normally distributed a non-parametric test, The Wilcoxon Signed Ranks Test, was used to analyze differences in performance on the two measures. The results showed that median performance on MDSWs was significantly better than for PSWs ($z = -5.66$, $p = 0.00$).

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[19] Recent literature regarding the development of speech in normal hearing Australian children suggests that the average percentage consonant correct score for monosyllabic words and polysyllabic words of 7-year-olds is 96% and 91.63% respectively (James, 2006). In the current study, a broader measure of percentage words correct was used.

Table 5-3 Speech production group results on the adapted ACAP

Variable	*Mean*	*Median*	*Range*	*Standard Deviation*
Mono- and di-syllabic words: n = 46	93.92	100	65 – 100	8.29
Polysyllabic n = 46	76.80	83	11 – 100	20.69

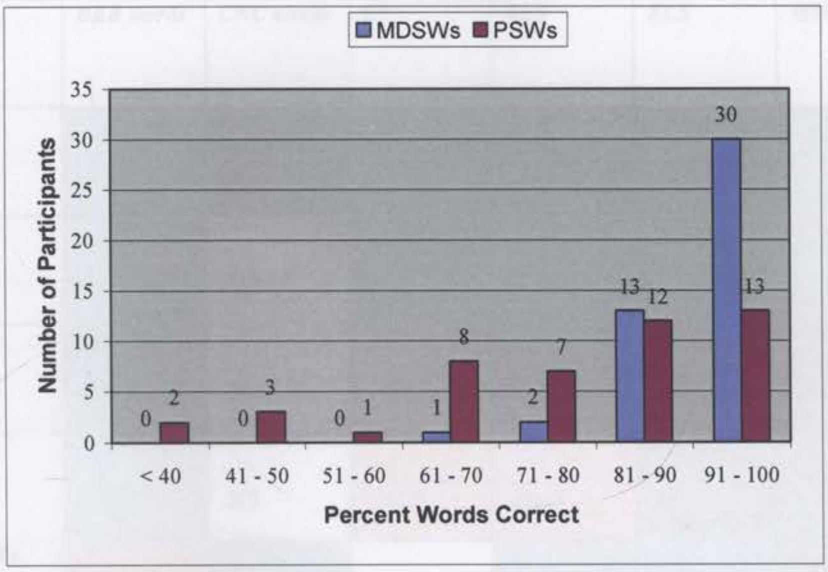

Figure 5-6 Distribution of scores for correct speech production of mono-disyllabic words (MDSWs) and polysyllabic words (PSWs) on the adapted ACAP.

5.5. Relationships between Speech Perception, Language and Speech Production Measures

The relationships between measures of speech perception, language and speech production are shown in Table 5-4. All measures of language were strongly correlated with one another. Both speech perception tests were significantly correlated with speech production. The sentence level speech perception measure (BKB words) was also significantly correlated with all language measures, whereas the single word speech perception measure (CNC words) was not significantly correlated with any language measure. Language measures, with the exception of receptive vocabulary with MDSWs, were significantly correlated with speech production, however the correlation was stronger for PSWs than MDSWs across language measures.

Table 5-4 Significant correlations between speech perception, language and speech production (p <.01)

	BKB words	*CNC words*	*RV*	*RLS*	*ELS*	*MDSWs*
CNC words	.531**					
RV	.447**	.318				
RLS	.534**	.363	.769**			
ELS	.444**	.228	.762**	.886**		
MDSWs	.614**	.457**	.349	.494**	.416**	
PSWs	.641**	.491**	.593**	.617**	.567**	.767**

*[*Red shaded boxes indicate variables that have a significant strong correlation. Blue shaded boxes indicate variables that have a significant moderate correlation.]*

RV = receptive vocabulary (PPVT-3); RLS = receptive language score (CELF); ELS = expressive language score (CELF); MDSWs = mono-disyllabic words; PSWs = polysyllabic words

5.6. Discussion

5.6.1. Speech Perception Outcomes

The tests of speech perception used in this study, as with most audiological speech tests, are not normed. The current study makes the assumption that children with normal hearing will be able to complete the speech perception tasks without error. This assumption is based on previous studies that have reported performance-intensity functions for word and sentence material. These studies show that performance increases with increases in intensity level, reaching asymptotic performance near 100% correct score at presentation levels under 70 dB SPL (Boothroyd, 2008; Brandy, 2002). In the current study the results for the speech perception tests indicate that the majority of participants have reduced auditory perceptual skills. On average they scored below 100% on both tests, with performance on isolated words poorer than for words in a sentence context. Recognition of words in isolation requires the ability to detect and interpret auditory cues within the speech signal. While the results of the participants in the current study are below those of children with normal hearing, their overall performance level of 64.7% on the open-set isolated word test (CNC words) suggests that they are developing perceptual abilities for speech. The better word recognition within a sentence context suggests that the participants can use contextual cues to improve their speech perception.

The results of the current study show wide variability in the outcomes achieved for speech perception. Two children scored above the group mean on the sentence level speech perception test (98% and 98%), but below the group mean on the word level test (62% and 54%). Both these children had language skills above the normal range. Such a finding suggests that even if auditory perceptual skills are compromised (as indicated by the low word level scores), it is possible for exceptional language skills to be developed. Further, these exceptional language skills are able to compensate for the poorer auditory perception and enable good recognition of words presented through audition at a sentence level. This finding, together with the significant correlations between language measures and BKB words support Blamey et al's (2001) conclusion that speech perception tests are a reflection of more than auditory ability and include language ability.

Interesting also is that the one child who scored 100% on the sentence level test scored below the normal range on language tests. This child was just over 10 years of age. According to Blamey et al. (2001) a language age of 7-years is necessary to perform well on the BKB sentence level test. While this child's language skills were below normal for a 10-year-old, they were sufficient to perform well on the sentence level test and suggest that at older ages at least, good auditory reception of words is not sufficient for good language development.

The findings of this study are consistent with the idea that a child with a cochlear implant does not receive the same acoustic information as a child with normal hearing, and consistent with previous studies that have reported reduced speech perception abilities for children using a cochlear implant. For example, Geers et al. (2003a) reported that children with a cochlear implant scored 56.8% on the BKB sentences, and between 44.2% (hard words) and 48.3% (easy words) on an isolated word test. These results are poorer than found in the current study. In another study, Blamey et al. (1998) reported the speech perception skills of a group of Australian children using a cochlear implant and oral communication. Despite specification of mode of communication similar to that used in the current study, Blamey et al's cochlear implant group obtained a mean score of 60% for BKB sentences, which was

28.4% below the mean of participants in the current study. For the CNC words Blamey et al reported a mean score of 48% in their auditory alone condition, which contrasts with 64.7% found for words in isolation in the current study. These differences in open-set speech perception results between these two previous studies and the current study may reflect differences in the characteristics of the participants of each study. Geers et al. (2003) found that the degree to which speech and audition were emphasized in a child's classroom contributed significantly to speech perception scores. The most obvious difference between the current study and the Geers et al study is the communication mode of participants. Participants in Geer et al's study used a range of communication modes, while participants in the current study used only oral communication. The difference in speech perception outcomes may suggest that children who use oral communication have greater ability to accurately perceive the sounds of spoken language. However, the results of the Blamey et al study call this conclusion into question. The participants in the Blamey et al study all used oral communication and yet their speech perception results were poorer than found in the current study. This result may reflect methodological problems inherent in the speech perception tests.

Theoretically speech perception tests measure a child's ability to detect and recognise the speech signal independent of his or her language ability. The tests are designed to minimize the contribution of language ability by using simplified stimuli including short simple sentences or isolated words with a simple consonant-vowel-consonant structure. Luce & Pisoni, (1998) in a study with normal hearing listeners found that frequency of occurrence of words affects word recognition performance. Kaiser, Kirk, Lachs and Pisoni (2003) confirmed this effect in users of cochlear implants. Word familiarity is a measure of how often a word is used in a language. The issue of word familiarity for children born with a significant hearing loss needs to be more carefully addressed. The CNC word lists were not constructed using word familiarity as a stimulus selection criterion. In addition the children in the current study had receptive vocabulary skills below the normal range. The CNC performance may therefore reflect an interaction of these two factors[20]. In contrast to the CNC word lists, the BKB sentences control for word familiarity based on the expressive vocabulary of children with a significant hearing loss. The reduced word recognition score on the BKB test suggest that the participants had reduced auditory perceptual skills, separate to their receptive vocabulary abilities.

Another methodological issue relevant in a discussion of the speech perception results is the mode of presentation of the stimuli. In the current study, the speech perception tests were administered via either recorded or monitored live-voice testing. Monitored live-voice testing was used for younger children or when a child did not attend to the recorded test. Live-voice testing is subject to variation as a result of the articulation characteristics of the presenter as well as variability in the presentation level of each stimulus item through unintentional changes in vocal effort. While the effects of these factors are uncontrolled they may be systematic, if, for example, the presenter had articulatory characteristics of clear speech or was familiar to the listener. The listener's familiarity with a speaker can improve speech intelligibility scores (Nygaard & Pisoni, 1998). These results suggest the need for standardised and recorded speech perception tests to be developed and used.

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[20] The correlation between CNC words and receptive vocabulary was not significant. However this does not rule out vocabulary being a factor in performance on this test. The receptive vocabulary test was standardised and therefore an older child may have had a poorer receptive vocabulary standard score than a younger child, but still have a larger vocabulary than the younger child.

Another factor that may have contributed to the differences in the outcomes of the two studies is the more recent date of data collection for the current study. The Blamey et al study was published in 1998 based on data collected over the previous year. The average age of participants was 7.7 years. The number of participants that initially used the MPEAK processing strategy was not reported, however the years that many of the participants were implanted covered the period of the change-over from MPEAK to SPEAK processing strategy. The current study had participants with longer use of more recent implant device and programming strategies.

In addition, the participants in the Blamey et al study used a range of approaches to the development of oral communication, while the current study more strictly specified participation in AVT. Finally, the participants in the current study were on average 12 months older at the time of assessment than the children in the Blamey et al study. This age difference may be associated with better developed language skills to support their performance on the speech perception tasks.

The results highlight the need to develop new, standardised speech perception procedures and tests that can assess perceptual development and changes in discrimination and recognition, while minimizing or controlling for the influence of other skills such as receptive language, particularly vocabulary skill. Open-set tests of spoken word recognition have been used in cochlear implant clinics as well as research as the accepted *gold standard* for measuring outcome and benefit. These tests measure the basis of what Summerfield and Marshall (1999) call the cascading hierarchy of benefits from an implant. They reflect not only speech perception but also other processes that contribute to speech perception including verbal rehearsal and endurance of phonological representations in working memory and retrieval of phonological representations from the lexicon, as well as phonetic implementation strategies required for speech production, motor control and response output (Pisoni, 2004). This is highlighted by the current findings of significant correlations between speech perception measures, and language and speech production measures. It would seem that improved measurement of speech perceptual processes is critical to our understanding of the large individual differences in outcomes achieved with a cochlear implant.

5.6.2. Language Outcomes

The majority of the children in the current study were attending mainstream education classes and all used oral communication. This suggests that the point of reference for comparing their language outcomes should be their peers with normal hearing rather than children with a significant hearing loss. The use of norms attained by typically developing children sets a high standard for children who are born with a significant hearing loss or who acquire a significant hearing loss prelingually. The use of language norms developed for children with normal hearing has been used in other research studies of outcomes for pediatric cochlear implantation (e.g., Blamey et al., 2001; Fagan et al., 2007; Geers et al., 2003b).

The outcomes for each area of language studied (receptive vocabulary, receptive language, and expressive language) indicate that the participants' hearing loss has impacted on their language development, with the majority achieving language skills below the normal range for their age in all three areas. These results are consistent with the few studies that have investigated the language skills of children using a cochlear implant (Blamey et al., 1998; Connor et al., 2000b; Dawson et al., 1995; Fagan et al., 2007; Geers et al., 2003b). Two of these earlier studies (Connor et al., 2000b; Geers et al., 2003b) identified contributing factors to language outcomes including communication mode, educational setting, use of recent implant technology and age of implantation. The group of children in this study was selected to meet criteria for each of these areas. All were oral communicators, implanted early and used recent implant technology, and all had received intensive AVT post-implantation. Despite these controls on participant characteristics the results still reflect significant delay in language outcomes for the children using a cochlear implant. The pattern of results showing better performance on receptive language than expressive language was similar to a previous study by Blamey et al. (1998). However, the children in the Blamey et al study performed poorer than the participants in the current study on both receptive language (Blamey et al mean RLS = 75, current mean RLS = 83.15) and expressive language (Blamey et al mean ELS = 70, current mean ELS = 79.61). Further almost double the percentage of children on the current study had a receptive language score (RLS) or expressive language score (ELS) greater than 85, the lower limit of normal performance. This difference in performance for language measures was also found for measures of speech perception (see previous section). The difference may reflect the different methods of oral communication used by children in the two studies, or may be the result of more recent implant technology used by children in the current study, or differences in age of assessment and possibly age at implantation. Blamey et al do not report the number of children in their study who were implanted under 2 and 3 years of age. However, because age of implantation has continued to drop over the years it is likely that a greater percentage of the participants in the current study were younger at time of implantation than in the earlier Blamey et al study.

The language outcomes in the current study also show wide individual differences. For example, one child scored 2 standard deviations above the normal range on the expressive language subtest, whereas another six children scored more than 3 standard deviations below the normal range on this subtest. It is also interesting that all language measures are more strongly correlated with PSW production than MDSW production. As discussed in chapters 1 and 2, PSW production has been linked with reading outcomes and may reflect underlying phonological processing abilities rather than speech motor difficulties. In children with normal hearing, children's differing abilities in processing of phonological information have been related to speech and language and reading outcomes. Oral language skills are have been found to contribute to phonological awareness development (Cooper, Roth, Speece, & Schatschneider, 2002), which in turn has a direct relationship with word reading (e.g., Ehri et al., 2001; Hogan et al., 2005; Muter et al., 2004; Wagner et al., 1997). In addition oral language skills are thought to have a direct relationship with reading comprehension (Catts et al., 2006; Muter et al., 2004; Roth et al., 2002a; Stothard & Hulme, 1992). Understanding the complete picture of skills of children using a cochlear implant may help to explain their poor reading comprehension outcomes. The profiles of the participants' phonological processing abilities are presented in chapter 6 and the relationships between reading, speech, language and phonological processing are addressed in chapter 7.

5.6.3. Speech Production Outcomes

A noteworthy finding of this study is the speech production ability for short words exhibited by this group of children using a cochlear implant. Their ability to produce simple MDSWs is nearing perfect production. Their median *word correct* score for MDSW production was 100%, and above the median *consonant correct* score for 7-year-old children with normal hearing. While the mean age of the cochlear implant group was 8.75 years, which is above the maximum age for the norm data, their performance on MDSWs suggests they are at a comparable level to their peers with normal hearing. This result is better than the speech production results that have previously been reported for children using a cochlear implant (Blamey et al., 2001; Connor et al., 2000b; Tobey et al., 2003). However, these differences may be a result of methodological issues, rather than reflecting differences in ability levels. The current study focused on the effect of word length on production while other studies of speech production outcomes have typically focused on the percentage of phoneme or consonants correct for stimuli that predominantly included monosyllabic and disyllabic words. The current study isolated and compared MDSWs with PSWs. The results show that the children in this study had more difficulty producing PSWs than shorter MDSWs. In children with normal hearing there is a developmental change between the ages of 3 to 7 years in their ability to produce PSWs (James, 2006). At age 5, the median consonant correct score for Australian children with normal hearing is 92% for monosyllabic words (MSWs) and 89.73% for PSWs and by age 7 these median scores increase to 96% for MSWs and 91.63% for PSWs. In the current study, the children's productions were scored for using a more stringent criterion of percentage words correct rather than consonants correct. The high percentage consonant correct scores of children with normal hearing imply they would also produce most PSWs correctly. The mean correct PSWs score by the children in this study of 76.80% is likely to be below what Australian children with normal hearing would achieve.

More interesting than comparing exact figures of consonant or word correct scores is the relative performance on production of MDSWs and PSWs, showing that PSWs were more difficult. This finding has not been previously studied or reported in children with cochlear implants. Difficulty with production of PSWs has been linked to poor reading outcomes in children with normal hearing (Larrivee & Catts, 1999) and the ability to process phonological information has been linked with problems in production of PSWs (Katz, 1986; Swan & Goswami, 1997b). For example, Katz (1986) hypothesised that poorly specified lexical phonological representations might underlie the observed difficulties in both reading and PSW production. The finding of a significant difference between MDSW production and PSW productions reveal the need for studies regarding the speech production skills of children using a cochlear implant to include a greater number of PSWs. The children in the current study rely on spoken language for communication and their greater difficulty producing PSWs compared to shorter words may reflect limitations in their phonological processing abilities. The following chapter (chapter 6) examines the profile of the children's phonological processing abilities.

5.6.4. Conclusions

The results indicate that relative to their peers with normal hearing the participants using a cochlear implant had reduced auditory perceptual skills, poorer language skills, and poorer speech production for polysyllabic words. According to Summerfield and Marshall (1999) reduced auditory perceptual skills, as indicated by poor speech perception scores, should impact on higher level spoken and written language skills. From a developmental perspective, a child builds their spoken vocabulary and language skills from hearing the sounds and structures of the language spoken in context around them. While the speech perception scores of these children are poor, it has been discussed that there are limitations in the measures used to examine speech perception and the results are likely to be a reflect output skills such as language rather than just auditory perception ability. Even with the limitations of speech perception considered, the scattered profile of areas of strength amidst areas of weakness in spoken language processing is somewhat puzzling. Why do these children present with good speech production for short words and yet experience difficulty accurately producing longer polysyllabic words? It appears there is a complex interaction of processes occurring between the receiving of spoken language and the processing, storage and retrieval. Investigation of these children's processing phonological abilities could provide information to assist in piecing together the puzzle and build a more complete picture of how these children process spoken language. The phonological processing abilities of the children may help to explain why some children present with good skills in some areas and yet poor in others and why some children might achieve considerably better outcomes than other children. The next chapter profiles the participants' phonological processing abilities and begins to explore some of these issues.

Chapter 6. Results and Discussion: Phonological Processing Profiles

6.1. Profiles of Phonological Processing Outcomes

The ability to encode, store and retrieve phonological information is essential for the development of spoken language (Fromkin, Rodman, Collins, & Blair, 1990). The processing of phonological information as well as the ability to explicitly reflect on phonological information has frequently been linked to reading development in children with normal hearing (e.g., Hogan et al., 2005; Perfetti & Sandak, 2000; Rvachew & Grawburg, 2006; Torgesen, 2000; Wagner et al., 1993). The cochlear implant aims to provide access to phonological information via audition for children with a significant hearing loss. However, children with normal hearing who have auditory access to phonological information from birth vary in their phonological processing abilities (Wagner et al., 1997). This chapter presents a comprehensive profile of the phonological processing abilities of 47 children using a cochlear implant. In the present study, phonological processing abilities included phonological working memory, phonological awareness and phonological retrieval. While previous research has reported on aspects of phonological processing, none has investigated the range of phonological processing abilities in children using a cochlear implant and compared them to norms established for typically developing children.

The participants' profiles of the different aspects of phonological processing may provide helpful information for exploring factors related to the participants' reading outcomes, as documented in chapter 4, and language and speech production profiles documented in chapter 5. Chapter 6 answers the question: What are the phonological processing (phonological working memory, phonological awareness and phonological retrieval) abilities of oral communicating children using a cochlear implant? This chapter addresses the hypotheses that the participants (oral communicating children using a cochlear implant that have participated in AVT):

- will have better phonological processing abilities than children using a cochlear implant in previous research who have used more visual communication approaches.
- will have poorer phonological processing abilities than children with normal hearing because the participants do not have *normal hearing* and have experienced a period of auditory deprivation.

6.2. Phonological Processing Results

Measures of each of the three areas of phonological processing (phonological working memory, phonological awareness and phonological retrieval) were obtained using the Comprehensive Test of Phonological Processing (CTOPP, Wagner et al., 1999). All 47 participants (24 boys and 23 girls) completed the version of the test appropriate for their age and composite scores were derived based on the test norms for each aspect of phonological processing. The mean composite standard score for the group of children in each area of phonological processing examined by the CTOPP are presented in Table 6-1.

Table 6-1 Phonological processing group results on the CTOPP

Variable	*Mean*	*Median*	*Range*	*Standard Deviation*	*Normal Range*
Phonological Awareness Composite SS n = 47	83.94	85.00	46 – 124	16.49	85 - 115
Phonological Working Memory Composite SS n = 47	78.83	79.00	49 – 142	16.91	85 -115
Rapid Automatized Naming Composite SS n = 47	92.68	94.00	59 – 124	12.65	85 - 115

The results show differences in performance for the group on each task relative to their peers with normal hearing, with the group achieving a mean score within the normal range only for phonological retrieval (measured using rapid automatized naming). The distribution of standard scores for all the areas of phonological processing is presented in Figure 6-1, and the distribution of standard scores for the three separate areas of phonological processing are presented in Figures 6-2, 6-3 and 6-4. The distribution of scores on rapid automatized naming shows that over three quarters (76.6%) of the participants obtained scores within or above the normal range. This contrasts with their performance on phonological working memory, on which the mean group score is well below the normal range and only 36.1% of the group achieved a composite standard score within the normal range. The mean score of the group for phonological awareness falls just below the normal range but the distribution indicates that slightly more than half the group (53.2%) achieved a phonological awareness composite standard score within or above the normal range.

Visual inspection of the Q – Q Plots (Appendix I) shows that, with the exception of one outlier on the phonological working memory measure, the scores on the three phonological processing measures are normally distributed.

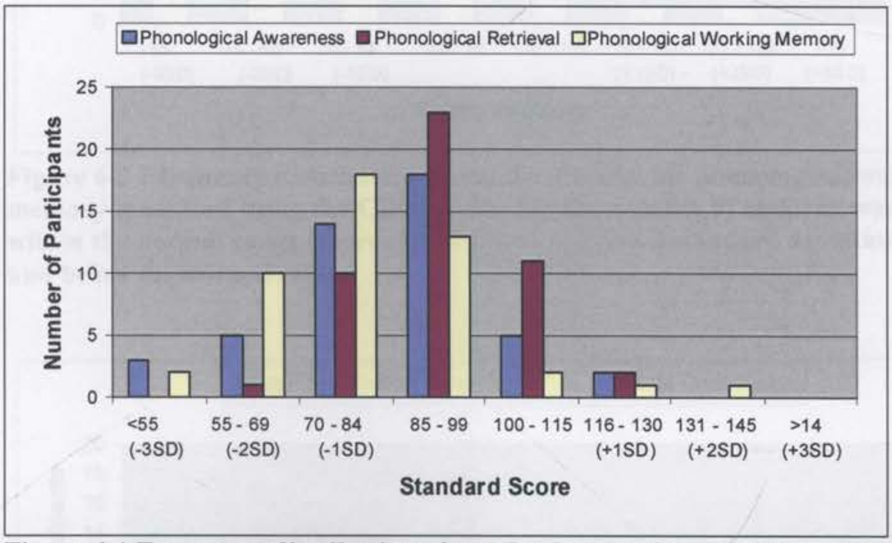

Figure 6-1 Frequency distribution of standard scores for phonological processing measured using the CTOPP showing the number of children who fell within the normal range (scores 85 - 115), or 1, 2 and 3 standard deviations above and below the normal range.

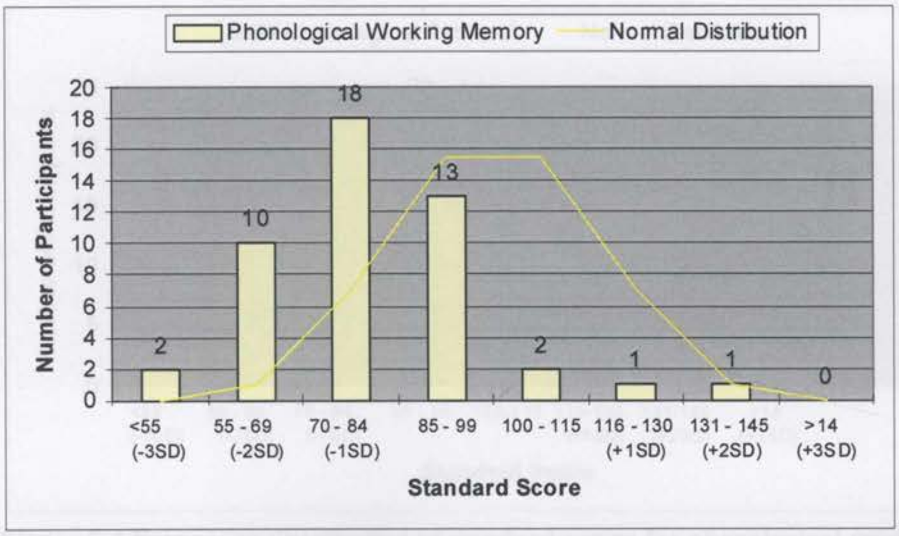

Figure 6-2 Frequency distribution of standard scores for phonological working memory measured using the CTOPP showing the number of children who fell within the normal range (scores 85 - 115), or 1, 2 and 3 standard deviations above and below the normal range.

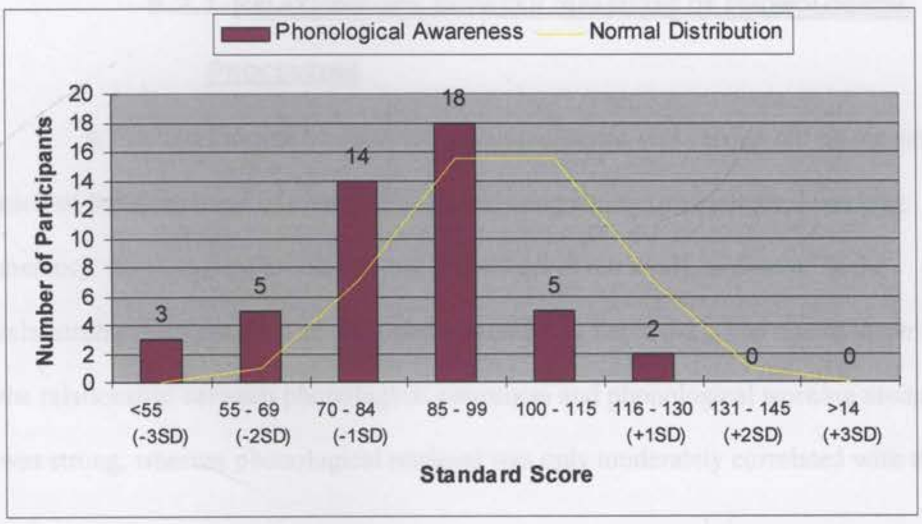

Figure 6-3 Frequency distribution of standard scores for phonological awareness measured using the CTOPP showing the number of children who fell within the normal range (scores 85 - 115), or 1, 2 and 3 standard deviations above and below the normal range.

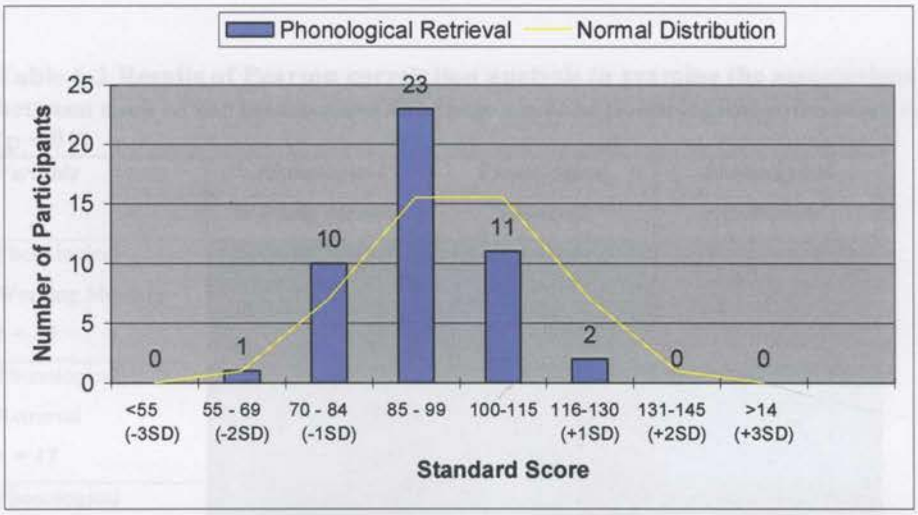

Figure 6-4 Frequency distribution of standard scores for phonological retrieval measured using the CTOPP showing the number of children who fell within the normal range (scores 85 - 115), or 1, 2 and 3 standard deviations above and below the normal range.

6.2.1. Relationships Between Measures of Phonological Processing

A Pearson Product Moment Correlation analysis was carried out on the results of each of the three areas of phonological processing ability (phonological working memory, phonological awareness and phonological retrieval), to determine the relationship between each of these abilities (refer to Table 6-2). The results show that the relationship between phonological awareness and phonological working memory was strong, whereas phonological retrieval was only moderately correlated with them.

Table 6-2 Results of Pearson correlation analysis to examine the associations between each of the measures of the three areas of phonological processing abilities (p <.01).

Variable	*Phonological Working Memory*	*Phonological Retrieval*	*Phonological Awareness*
Phonological Working Memory n = 47		.555	.684
Phonological Retrieval n = 47			.443
Phonological Awareness n = 47			

*[*Red shaded boxes indicate variables that have a significant strong correlation. Blue shaded boxes indicate variables that have a significant moderate correlation.]*

6.3. Discussion: Phonological Processing Outcomes

6.3.1. Phonological Working Memory

Overall the results indicate that the children in this research had poor phonological working memory abilities compared with children with normal hearing. However, the range of scores showed a wide range of abilities between participants. The finding that a third of the children performed at or above the normal range suggests that some children with a significant hearing loss can accurately maintain phonological information in working memory. Two children demonstrated outstanding phonological working memory abilities, scoring 1 and 2 standard deviations above the mean. Nevertheless, the low scores of the majority of participants on tasks of phonological working memory indicate that compared to their peers with normal hearing, these children using cochlear implants have difficulty in either accurately encoding or maintaining information in phonological working memory, despite using oral communication.

Previous studies that have reported on the phonological working memory abilities of children using a cochlear implant have come from a group of researchers from Indiana University. This research group was involved in the series of studies reported by Geers and colleagues (2003) and except for Fagan et al. (2007)[21], the studies (Pisoni & Cleary, 2003; Geers, 2003; Cleary et al., 2002; Dillon et al., 2004; Dillon & Pisoni, 2006) included the same participants as in the Geers (2003) research (see section 2.4.2.1 for a review). The poor phonological working memory abilities of participants in the present study are consistent with findings of Pisoni and Cleary (2003) and Fagan et al. (2007), despite the use of different measures of phonological working memory between the studies and differences in participant characteristics. The participants in these previous studies are not directly comparable to the current study, as the previous studies with the exception of Fagan et al, did not use oral communication as an inclusion criterion. The study by Fagan et al included children who only used oral communication, but their study only had a small number of participants. There were also differences in the tests used to measure phonological working memory. In the present study the phonological working memory score was a composite of both digit span and repetition of nonwords. The current findings of phonological working memory cannot be compared to previous studies such as Dillon et al., (2004) and Dillon and Pisoni, (2006) as these previous studies used a non-standardised measure of nonword repetition accuracy. However, both Pisoni and Cleary (2003) and Fagan et al. (2007)

[21] It was not clear in the Fagan et al. (2007) article whether the participants were also part of the Geers (2003) larger project.

used the forward and backward digit span subtests of the WISC-111, a standardised test, as their phonological working memory task. Both of these studies reported that the span lengths of children using a cochlear implant were shorter than the digit span results of children with normal hearing. For example, Fagan et al reported that the group mean standard score on forward digit span was 6.5, which is greater than 1 standard deviation below the test mean of 10. It has been suggested that rapid presentation of forward digit span tasks stress the efficiency of the phonological loop of working memory (Wagner et al., 1999) and more accurately reflect the demands of conversational speech. The digits in the WISC 111 test that were used in the previous studies of working memory are presented at one digit per second, which is somewhat slower than the presentation of speech in everyday conversation. In the current study digits were presented twice as fast as the presentation rate of the digits of these previous studies, in keeping with the test protocol and the more natural, faster rate of conversational speech. The similarity of poor phonological working memory results in both the current study and previous studies using the WISC 111, suggests that presentation rate was not a determining factor for the poor results on phonological working memory.

The poor performance of children using a cochlear implant compared to typically developing children on tests of phonological working memory raises the question of why the encoding and brief retention of phonological sequences is so challenging. The children in the present study have been given access to phonological information through audition via the cochlear implant, they have received AVT that actively encourages the development of verbal rehearsal, and they communicate orally, the corollary of which is the processing of phonological information on a daily basis. Yet when it comes to being able to retain a novel phonological sequence or sequence of digits many of them struggled. In chapter 2, a theory that the capacity of the phonological working memory is affected by the encoding process was reviewed (Gathercole, 2006; Vance & Mitchell, 2006). One possible reason for the poor phonological working memory ability of children using a cochlear implant is that encoding the speech signal is more difficult for them than children with normal hearing. If these children have to dedicate more cognitive resources to encoding the phonological information it is possible they have less cognitive resources left for the retention of this information. While such a theory helps to explain the low phonological working memory scores of the majority of participants, it does not account for three children who in spite of a reduced auditory signal achieved exceptional performance (see Figure 6-1). Two of these children performed above the normal range on the phonological working memory task, while the third child scored 112, which is close to the upper boarder of the normal range. All three children were fitted with hearing aids at a relatively young age <10 months, they all used the more recent Nucleus 24 implant with the ACE processing strategy and their mothers had tertiary level education. No other children in the participant sample shared all four of these characteristics, however the data do not enable us to explore this issue further. Perhaps there is an early sensitive period in the development of phonological working memory or perhaps aspects of intervention influences the development of phonological working memory. For example, it is possible that educators working with children using a cochlear implant in the early years focus on providing acoustic highlighting, using performatives and shorter words to establish the initial representations, but then fail to reduce the acoustic highlighting and use longer words. These are potential areas for future research to explore.

Another question arising from these results is what might be the effects of a reduced phonological working memory? As reviewed in chapter 2, a deficit in phonological working memory theoretically has implications for the children's ability to learn new vocabulary and ability to convert printed material into phonological codes. Deficits in the processes that contribute to the transfer of information to or from the lexicon are likely to impede the accurate long-term storage of information. A deficit of phonological working memory may make the transfer of phonological information into the long-term memory challenging. As discussed in chapter 2 previous research of children with normal hearing has proposed that phonological working memory is linked to vocabulary development (Gathercole et al., 1997), speech production (Adams & Gathercole, 1995) and reading ability (Passenger et al., 2000). The children in this study also have poor receptive vocabulary skills (see chapter 5). This suggests the need to explore the relationship between phonological working memory and reading, speech and language, if the abilities of children who use a cochlear implant are to be understood. This issue is addressed is chapter 7 of this thesis.

6.3.2. PHONOLOGICAL AWARENESS

Just over half of the children achieved a phonological awareness composite score within or above the normal range. This essentially means that about half the children have age appropriate explicit awareness of the phonological forms of English, as well as phonological representations specified to a level commensurate with the phonological awareness task. The tasks comprising the phonological awareness composite score were an elision and blending task for all participants, as well as a sound-matching task for the 5- and 6-year-old participants. These tasks were at a phonemic level, with the exception of the first three items, and success on these tasks required the children to use a phonological strategy. The results indicate that the majority of the participants have the underlying phonemic awareness skills to draw upon when utilizing a phonological coding strategy for word reading. A finding reiterated by the children's relatively good performance on the phonemic decoding reading task detailed in chapter 4.

The present study extends the work of Fagan et al. (2007), which is the only other study that has used a standardised measure to report group results and profiles of the phonological awareness performance of children using a cochlear implant. Direct comparisons with the Fagan et al study are confounded by the use of different tests of phonological awareness (limitations in the Fagan et al study were discussed in chapter 2). The current study used a broader measure of phonological awareness that was not supported by a visual medium. Fagan et al reported that the mean standard score of the participants in their study was just within the normal range, however no information was provided about distribution of scores. In the present study the group mean phonological awareness score was just below the normal range, while the median score was within the normal range. The slightly higher group mean score in the Fagan et al may be a result of the small number of children in their study. The current study contains almost twice as many participants as the Fagan et al study. Reflecting the phonological awareness skills of a greater number of cochlear implant users, the group scores in the current study would be less affected by extreme individual performances. In addition, the average age of the participants in the Fagan et al study was older at the time of assessment, and they received their implant at a slightly younger age and had been using their cochlear implant for about a year longer than the participants in the current study. All or some of the above factors may account for the small difference between group mean scores of the two studies. However, it is also likely that the use of quite different measures of phonological awareness also account for the different results. It is possible that because children in both studies have poor phonological working memory abilities, the phonological awareness task used by Fagan et al, which included a visual medium in the form of coloured blocks, supported the participants' completion of tasks.

The children in this study demonstrated better phonological awareness abilities than previously have been documented for groups of children with significant hearing loss without a cochlear implant (Harris & Beech, 1998; Izzo, 2002; Miller, 1997). However, almost half of the participants had abilities poorer than children with normal hearing. As discussed in chapter 2 one theory is that vocabulary expansion drives lexical restructuring and refinement of phonological representations (Griffiths & Snowling, 2001; Metsala, 1997; Walley et al., 2003). Phonological representations are believed to be reflected upon in phonological awareness tasks. Weak phonological awareness abilities could thus signify a weakness in either metalinguistic abilities or the specification of one's phonological representations. It is interesting that a greater proportion of the participants had phonological awareness scores commensurate with children with normal hearing than phonological working memory or language scores. Research studies have reported that, in children with normal hearing, intervention that incorporates phonological awareness activities can have a positive effect on both phonological awareness abilities (Gillon, 2002, 2005; Roth, Troia, Worthington, & Dow, 2002b; van Kleeck, Gillam, & McFadden, 1998) and reading outcomes (Ehri et al., 2001; Gillon, 2000; Gillon, 2002, 2005; Kirk & Gillon, 2007). For example, Gillon (2005) reported that 3-year-old children with significant speech difficulties who received intervention focused on the development of phoneme awareness and letter-sound knowledge can achieve phonological awareness and word reading skills equal to or above the normal range at around 6 years of age.

What might be interesting to consider is whether the AVT sessions attended by the children in the current study facilitated their phonological awareness development, which in turn may have supported their word reading development. In AVT parents are coached in highlighting sound contrasts and helping their children attend to and become aware of the sounds of words. It may be that the therapy process promoted an explicit awareness of sounds for some of these children. However because specific characteristics of intervention, such as amount, duration and content, were not the focus of this thesis the data does not enable further exploration of this issue. A potential area for future research to explore is the effect of specific training in phonological awareness on the phonological awareness abilities and/or reading abilities of children using a cochlear implant.

6.3.3. Phonological Retrieval

While the rapid automatized naming task has been commonly used in children with normal hearing to examine their phonological retrieval abilities, this is the first study to use it with a group of children using a cochlear implant. Remarkably most of the children in this study presented with good phonological retrieval of highly familiar vocabulary. In the task of rapid automatized naming the participants were shown a set of repeated familiar stimulus pictures that they had to name in the shortest possible time. The majority of participants were able to complete this task within normal limits and this finding suggests that they are able to access phonological codes from visual input and efficiently retrieve and produce known words; that is words stored in their lexicon. This finding is similar to the results reported by Dyer et al (2003) in a study of deaf adolescents who were not cochlear implant users.

As discussed in chapter 2, performance on rapid automatized naming tasks has been linked with word reading. Although there is one opinion that common non-phonological skills underlie the relationship between performance on rapid automatized naming tasks and reading (Wolf, 1991; Wolf & Bowers, 2000), others have viewed the relationship as primarily phonological in nature (Griffiths & Snowling, 2001; Swan & Goswami, 1997b; Wagner et al., 1999). Whether a primary measure of phonological retrieval or also a measure of nonphonological skills, the finding that the majority of participants performed within normal limits on the rapid automatized naming task suggests that their phonological retrieval skills are well developed. Further, for the participants to efficiently and accurately retrieve the words, the words must have adequate phonological representations within long-term memory. The stimulus words for the phonological retrieval tasks were purposefully short common words so to examine phonological retrieval rather than the underlying representations. However the findings also confirm that the participants' phonological representations of short common word may be well specified. In chapter 5 it was found that the participants had more difficulty accurately producing polysyllabic words than shorter words. These findings suggest that for many of the children less frequently heard, longer or later acquired words might not have well-specified phonological representations.

6.3.4. Relationships Between Measures of Phonological Processing

The relationships between all three measures of phonological processing (see Table 6.2) are consistent with findings of children with normal hearing. In children with normal hearing all three of the stated aspects of phonological processing (phonological working memory, phonological awareness and phonological retrieval) have been shown to be related to each other but separable by their unique features and discernible contributions to reading (Wagner et al., 1999; Wagner et al., 1997). In this thesis the three measures of phonological processing were significantly correlated, however the differences in the group mean scores of the measures support that they are separate aspects of phonological processing.

6.3.5. SUMMARY

Few studies have examined the phonological processing abilities of children who use a cochlear implant. The results reported in this chapter reflect an uneven profile of phonological processing abilities. There was variability in the group outcomes across the three different measures of phonological processing, and a wide variation across participants within each measure. For example, within the measure of phonological working memory, the standard scores ranged from 49 to 142. Overall, the children exhibited good phonological retrieval and reasonable phonological awareness abilities in spite of poor phonological working memory ability. Phonological awareness and phonological working memory had a strong significant correlation, and phonological retrieval had a moderate significant correlation to phonological awareness and phonological working memory. It is possible these findings may explain some of the differences in the language, speech production and reading outcomes of the participants.

In chapter 4 it was reported that demographic factors were not largely related to reading outcomes. The literature in children with normal hearing suggests that phonological processing abilities are predominantly related to word reading, and that reading comprehension is a product of word reading and language skills. To assist in directing the focus of intervention and focus of future research, it is important to establish what skills are related to word reading and reading comprehension outcomes in oral children using a cochlear implant. Isolating one or two areas in research or intervention may lead to more crucial skills being overlooked. The need to provide a big picture of the relationships between outcomes for these children is addressed in chapter 7 of this thesis.

Chapter 7. Results and Discussion: Relationships

"To be literate is to be included in the wealth of human endeavour and creativity. To be illiterate is to be excluded, with the sense of being deprived of the vital ingredients for growth and emotional well-being".

(Neale, 1999, p.1)

This thesis began with two aims. Firstly to provide comprehensive profiles of the reading and phonological processing abilities of school-aged children who use a cochlear implant and communicate orally. Secondly, to explore what skills might be related to reading outcomes and to present a big picture view of the relationships between the children's performance on tasks of reading, speech perception, speech production, language and phonological processing. The results presented in chapter 4 indicate that overall the reading comprehension of 47 children using a cochlear implant was poor relative to hearing peers, while word reading outcomes were good for word list tasks, but poorer for passage length text. For both word reading and reading comprehension the results showed great variability in the abilities of the children despite their relatively homogeneous oral education background and use of a cochlear implant. This chapter explores factors that may have contributed to these reading outcomes and the factors that may underlie this variability.

The low reading comprehension achieved by the majority of the children, all of whom are in mainstream education, is of concern. Demographic, implant-related or audiological factors that have been previously reported as influencing outcomes, except for size of family, were not an issue (see section 4.2). Previous literature reviewed in chapters 1 and 2 suggests that speech and language abilities might influence reading outcomes. In chapter 5 the speech perception, speech production and language outcomes of the participants were profiled. It was reported that expressive and receptive language skills as well as vocabulary knowledge were poor for many participants, but again there was great variability between participants. Mono- disyllabic word production was very good for most participants, while production of polysyllabic words was more challenging and again there was variability between participants. The association of phonological processing ability and reading has been examined extensively in the literature on children with normal hearing, but has received limited attention in literature of children using a cochlear implant. This thesis addresses this gap in the literature. In chapter 6, the phonological processing abilities of the children were reported and again variability was a feature of the results obtained. This variability was seen in the group across the different areas of processing assessed as well as amongst participants. The results indicated that overall the children performed better on measures of phonological retrieval and phonological awareness than on measures of phonological working memory.

These results highlight that outcomes of children using a cochlear implant are complex. If factors contributing to reading outcomes are to be understood there is a need to explore if, and how, outcomes in all areas are related. This chapter draws together the results reported in previous chapters for each of the separate areas to examine their relationship to reading in oral communicating children using a cochlear implant. This chapter goes beyond previous research by including the contribution of underlying phonological processing abilities to each of the other outcome areas.

The question addressed in this chapter is: What are the relationships between reading and spoken language measures? It is hypothesised participants (oral communicating children using a cochlear implant that have participated in AVT):

- with better word reading and language skills will have better reading comprehension outcomes.
- with better phonological processing abilities will have better word reading outcomes.
- with larger vocabularies will have better phonological processing abilities.

7.1. Results:

7.1.1. Relationships of Reading and Phonological Processing and, Speech Perception, Language and Speech Production

The first analysis used two separate Pearson Product Moment correlations to examine the relationship between each of the major areas investigated. The first correlation focused on reading and analysed the relationship between the measures of reading and results for speech perception, speech production, and language. The second correlation focused on phonological processing and examined the relationship between the measures of phonological processing and results for reading, speech perception, speech production and language. As a check on bivariate assumptions (linearity and absences of bivariate outliers), scatter plots were drawn of all variables. Visual inspection of the scatter plots was used to verify the significance of the correlation coefficients found (for the more relevant scatter plot graphs see Appendices J & K). The scatter plots show the expected spread of points around the function (Martin, 1991). However, the scatter plots show that some of the relationships are curvilinear rather than linear (e.g., Appendix J i). In addition, there were outliers in some of the scatter plots (e.g., Appendix J ii, iv, vi), although the outliers did not affect the strength of the correlations.

7.1.2. Summary of Relationships with Reading Measures

The results from the correlation analyses (see Tables 7-1 and 7-2) revealed significant relationships between measures of phonological processing and reading, language and speech production. There were strong significant correlations between all measures of reading and all measures of language and phonological awareness (refer to Table 7-1). Phonological awareness was also strongly correlated with all measures of language and polysyllabic word production. Examination of the scatter plot graph of language and reading comprehension (Appendix J i) shows a slight curvature to the relationship. The flat relationship between the first few data points reflects that a minimum level of language competence is required for reading comprehension.

Polysyllabic word production and rapid automatized naming were also strongly correlated with phonemic decoding efficiency and moderately correlated to all other reading measures. The single word speech perception task (CNC words) was not significantly correlated with any measure of reading, and the sentence level speech perception task (BKB words) was only moderately correlated with passage level reading measures and phonemic decoding efficiency.

Phonological working memory was moderately correlated to all measures of language ability, all single word reading tasks (phonemic decoding efficiency, sight word reading efficiency and nonword reading), speech production for polysyllabic words and the BKB speech perception test. However the correlations for phonological working memory and reading were weaker than those between reading and the other two phonological processing measures (phonological awareness and phonological retrieval).

There was no significant correlation between phonological working memory and reading measures for passage length material (i.e., reading accuracy and reading comprehension). Interestingly, the CNC words speech perception test was the only measure not significantly correlated with any of the phonological processing measures.

Table 7-1 Significant correlations of measures of speech perception, language and speech production with measures of reading (p <.01)

	Variable	***Reading Accuracy***	***Reading Comprehn.***	***Nonword Reading***	***Phonemic Decoding Efficiency***	***Sight Word Reading Efficiency***
LANGUAGE	Receptive Language	.693	.812	.693	.777	.780
	Expressive Language	.717	.807	.797	.787	.756
	Receptive Vocabulary	.701	.706	.648	.777	.636
SPEECH PROD.	MDSWs	.497	.503	.332	.477	.462
	PSWs	.561	.588	.498	.647	.566
SPEECH PERCEPN.	CNC Words	.290	.337	.191	.264	.231
	BKB Words	.487	.509	.295	.383	.337

*[*Red shaded boxes indicate variables that have a significant strong correlation. Blue shaded boxes indicate variables that have a significant moderate correlation.]*

Table 7-2 Significant correlations between reading, language, speech production and speech perception and measures of phonological processing (p <.01)

	Variable	***Phonological Memory***	***Phonological Retrieval***	***Phonological Awareness***
Reading	Reading Accuracy	.361	.485	.703
	Reading Comprehension	.378	.493	.685
	Phonemic Decoding Eff.	.444	.627	.669
	Sight Word Reading Eff.	.454	.547	.684
	Nonword Reading	.412	.550	.638
Language	Receptive Language	.530	.510	.659
	Expressive Language	.591	.517	.769
	Receptive Vocabulary	.395	.413	.638
Speech Production	MDSWs	.348	.448	.595
	PSWs	.434	.476	.709
Speech Perception	CNC Words	.185	-.041	.224
	BKB Words	.432	.031	.476

*[*Red shaded boxes indicate variables that have a significant strong correlation. Blue shaded boxes indicate variables that have a significant moderate correlation.]*

7.1.3. What Skills are Related to Word Reading Performance?

Examination of the correlation coefficients (see Tables 7-1 and 7-2) reflecting the relative strengths of the relationships with word reading, revels that phonological awareness and language are both very strongly related to word reading. All of the measures that extensively utilize phonological information were moderately to strongly related to word reading, whereas (except for number of children, a nonlinear relationship) demographic, and audiological and implant-related factors were not related to word reading ability (refer to chapter 4, Table 4.4).

One way of analyzing the current data might be to conduct a multiple regression analysis to determine what variable/s most account for the variance in word reading outcomes. Doing such an analysis with the current data was considered and the idea rejected due to statistical limitations. The difficulty with a multiple regression analysis using the current data is that the high correlations between the independent variables (e.g., measures of phonological awareness, phonological working memory and language) would be likely to affect the stability of the analysis. Therefore, instead of conducting such an analysis, potential reasons for the strong correlations between variables were considered, and an alternative analysis conducted.

One possibility for the strong correlations between the variables (e.g., phonological awareness and language) is that the tasks are measuring the same underlying ability even though on the surface the tasks that comprise the individual measures are very different. To determine whether phonological awareness and language could be reduced to a single variable, a principal component analysis was conducted with phonological awareness and language as the extracted variables. The first principle of the analysis accounted for 81% of the variance in the scores suggesting that phonological awareness and language have common variance.

A scatter plot graph was then produced using the first principal component of word reading on the y-axis and the first principal component of language and phonological awareness on the x-axis (see Figure 7-1). This scatter plot reveals a strong linear relationship between the variables and suggests that the factor common to language and phonological awareness largely predicts word reading.

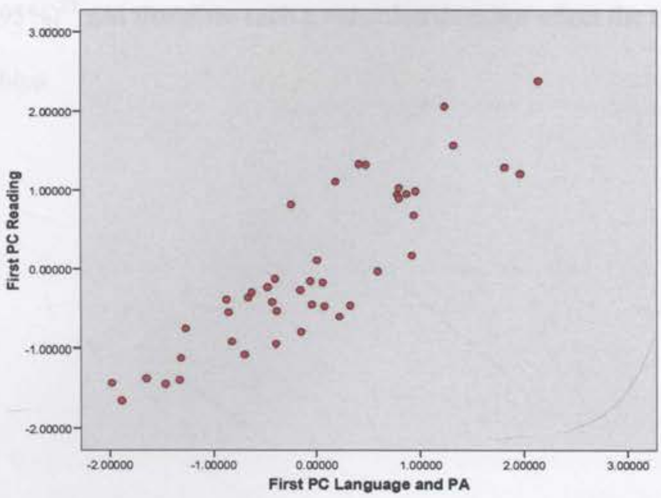

Figure 7-1 Scatter plot graph of the first principal components of language and phonological awareness plotted against word reading.

Figures 7-2 and 7-3 show an integrated overview of the relationships between word reading and reading comprehension with all the measures investigated in this research. Language and word reading in these figures have each been reduced to single variables by taking the first principal components. This was done to reduce the number of variables so that relationships between factors could be easily determined. The variables contributing to the first principal components of language (expressive language, receptive language and receptive vocabulary) and word reading (sight word reading efficiency, phonemic decoding efficiency and reading accuracy) were high (90% to 95%)[22] and therefore such a reduction does not affect the overall picture of relationships.

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[22] Extracted components for a) language: receptive language = .950, expressive language = .948, receptive vocabulary = .901, b) word reading: sight word reading efficiency = .901, phonemic decoding efficiency = .932, reading accuracy = .919.

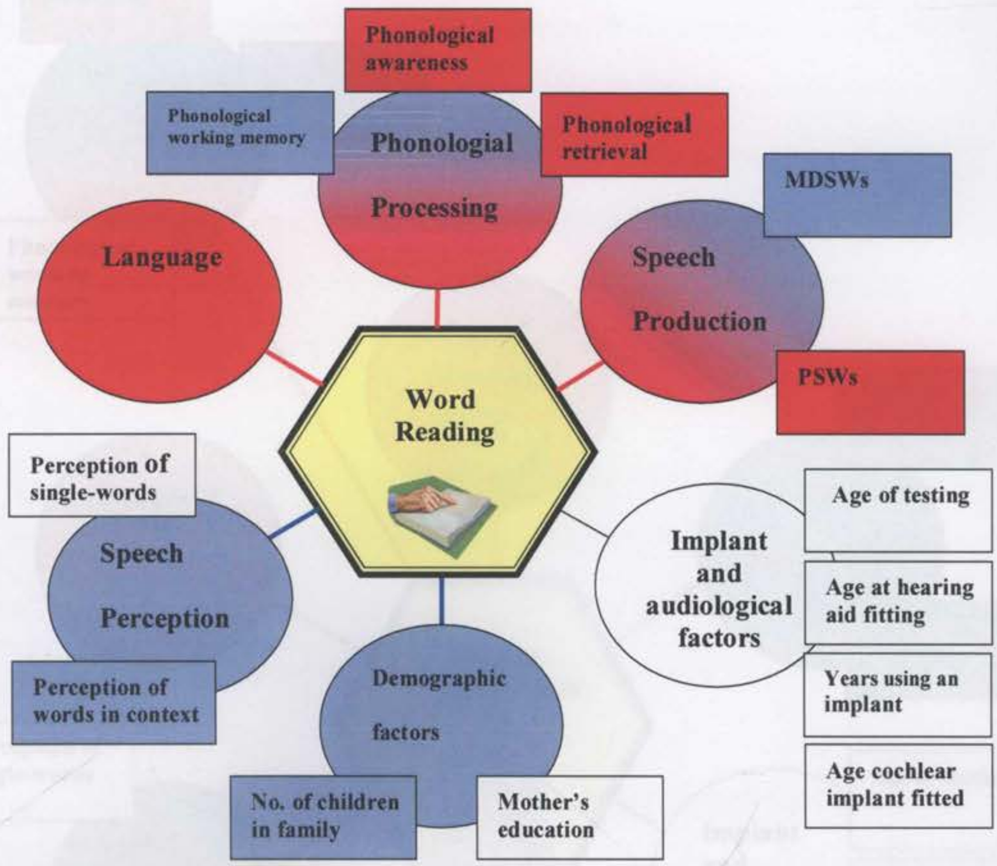


Figure 7-2 Relationships of speech, language, demographic, implant and audiological factors and phonological processing variables with word reading.
[Red shaded boxes and lines indicate variables have a significant strong correlation. Blue shaded boxes and lines indicate variables have a significant moderate correlation]

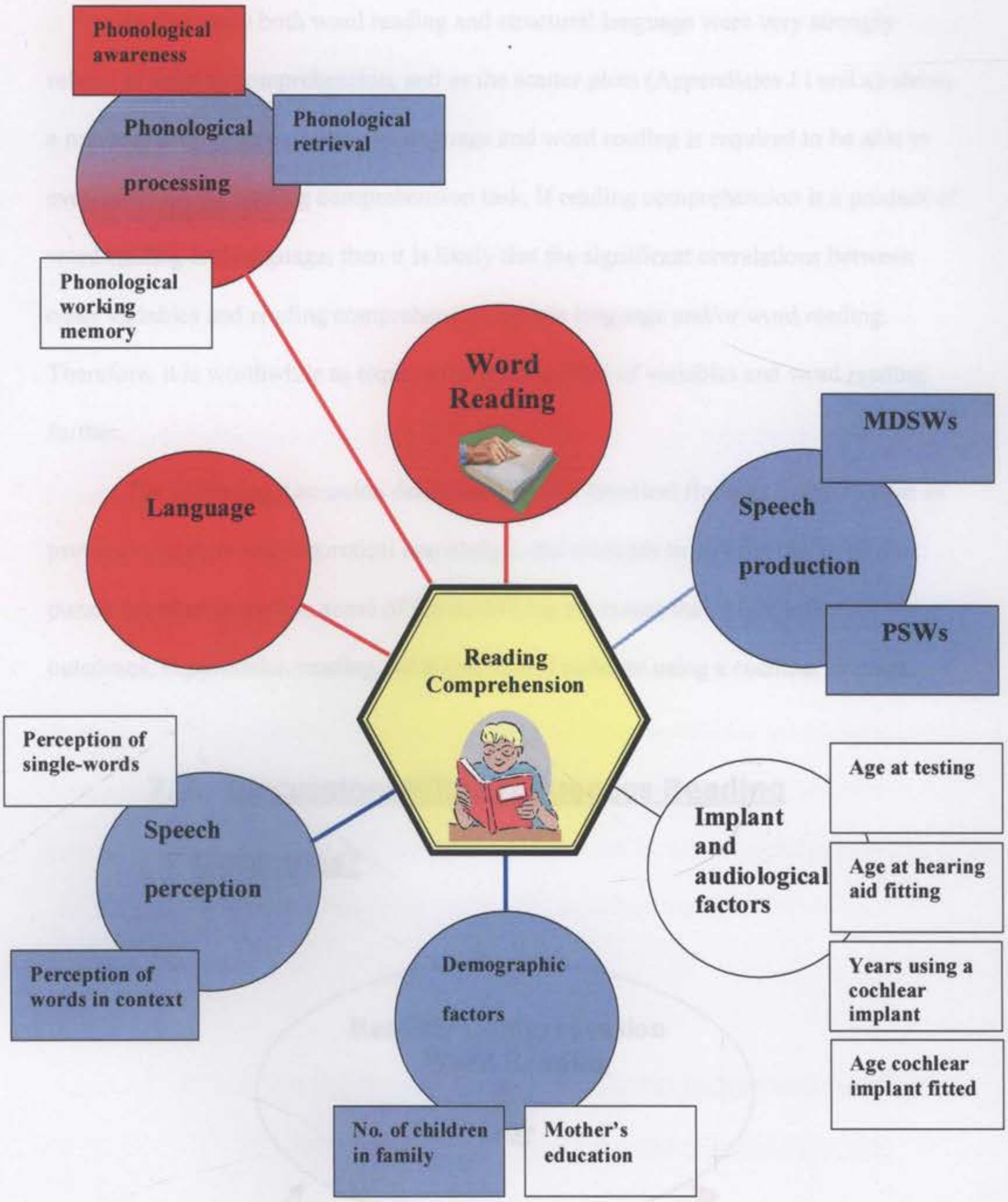
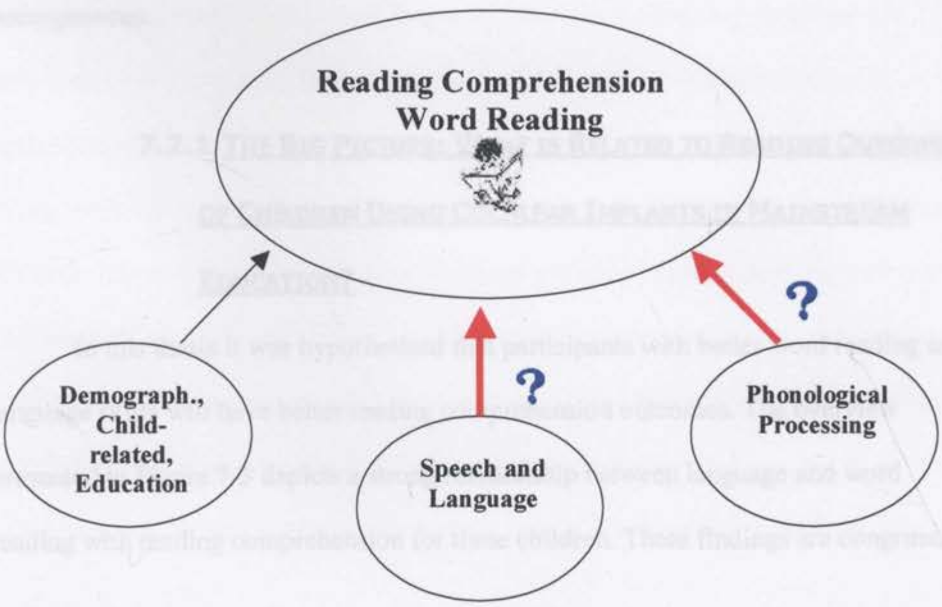


Figure 7-3 Relationships of speech, language, demographic, implant and audiological factors, phonological processing variables and word reading with reading comprehension. *[Red shaded boxes and lines indicate variables have a significant strong correlation. Blue shaded boxes and lines indicate variables have a significant moderate correlation.]*

In this study both word reading and structural language were very strongly related to reading comprehension, and as the scatter plots (Appendicies J i and x) show, a minimal level of competency in language and word reading is required to be able to even score on the reading comprehension task. If reading comprehension is a product of word reading and language, then it is likely that the significant correlations between other variables and reading comprehension are via language and/or word reading. Therefore, it is worthwhile to explore the relationships of variables and word reading further.

The following discussion deliberates on the statistical findings in the context of previous literature and theoretical knowledge, and attempts to pull the pieces of the puzzle together to explain some of the underlying processes that might influence the outcomes, in particular, reading outcomes of oral children using a cochlear implant.

7.2. Discussion: What Influences Reading Outcomes?



The results of this research provide information about the relationships between reading, spoken language and phonological processing abilities of a group of oral communicating children using a cochlear implant. There are two particularly important findings. The first of these is that language and reading are strongly connected; these children require a minimum level of language competence to be able to understand written text (see Appendix J i). The second is that the phonological processing abilities of the children are moderately or strongly correlated to most aspects of their reading and language. In a broad sense this information tells us that by and large those children that have better skills in encoding, storing, retrieving and reflecting on phonological information also have better skills in spoken language and reading.

Two distinct aspects of reading have been measured: reading comprehension and word reading. The following discussion explores the influence of each variable to reading comprehension and word reading, and examines possibilities for the underlying source of commonality to explain the relationships. The strength of this research is that several measures in the areas of interest (e.g., word reading, phonological processing and language) were obtained while demographic and educational factors were relatively homogeneous.

7.2.1. THE BIG PICTURE: WHAT IS RELATED TO READING OUTCOMES OF CHILDREN USING COCHLEAR IMPLANTS IN MAINSTREAM EDUCATION?

In this thesis it was hypothesised that participants with better word reading and language skills will have better reading comprehension outcomes. The overview presented in Figure 7-3 depicts a strong relationship between language and word reading with reading comprehension for these children. These findings are congruent with the simple view of reading (Hoover & Gough, 1990) reviewed in chapter 1. Examination of the scatter plot graphs of reading comprehension plotted against principal components of word reading (see Appendix J x) and language (see Appendix J i) show that all the children with low word reading or low language skills have low reading comprehension abilities. The crucial contribution of language to reading comprehension outcomes is not unexpected. Once the written message has been decoded it is in a similar form to spoken language. However there may be differences in the emphasis of aspects of language in spoken and written forms. The ability to infer and understand figurative language is particularly important for understanding written material (Nation, 2006). Only a small percentage of the questions in the Neale-3 can be answered from text information used literally (see Nation, 2006). Both inference and figurative language are typically poor in children with a significant hearing loss (King & Quigley, 1985). Interestingly, as can be seen in the scatter plots Appendix J i & ii while both vocabulary and broader receptive and expressive language skills are strongly related to passage reading comprehension, broader language abilities are more crucial for passage reading comprehension than vocabulary.

Reading is acquired subsequent to the acquisition of spoken language and language is therefore taken to be the causal variable, that is, children with good language skills have a good base for reading comprehension. The results support that a strong language base is necessary for good passage reading comprehension, skills that are generally poor in children with a significant prelingual hearing loss. However, as children get older they start to use written material to learn, and the direction of the relationship between language and reading comprehension may therefore be reversed or at least become more interactive. This study covered a broad age range across the years of primary school. From about 9 years of age, rather than learning to read, reading becomes a medium for learning about language (Pence & Justice, 2008), learning about the opinions of others and the world around us. Therefore there is also the possibility for reading comprehension limitations in earlier years to compound the language and reading gap between these children and their peers with normal hearing in later years. This is commonly known as the Mathew Effect (Catts & Kamhi, 2005). Specifically, those with good reading skills are more likely to enjoy reading, read more and learn more from reading, whereas those children with poor reading skills are likely to dislike reading, read less and be limited in the ability to use written text to further their knowledge of the world.

The relationship between word reading and reading comprehension has not often been looked at in this population. If the words in text are not read quickly and accurately it is unlikely meaning will be extracted from the words. Robertson (2000, p.41) states, "The processing of each word can become a tedious matter, so tedious in fact that the reader puts too much cognitive attention into the decoding of the shapes into sounds, and the result is simply making noises to go with symbols". Such a statement suggests that if word reading is not efficient then comprehension will be compromised. The word reading abilities of the children in this research were strongly related to their reading comprehension outcomes (refer to Table 7-1). There were strong relationships between reading comprehension and word reading accuracy on the Neale-3 as well as between reading comprehension on the Neale-3 and word reading efficiency on the TOWRE, indicating that those participants who have more efficient word reading generally, even if not related to the specific text, have better reading comprehension. This may be because these children who have well-developed, efficient word reading skills do not have to focus on decoding or recognising words and instead can attend to abstracting meaning from text. Although limited prompting of single words is suggested as part of the Neale-3 administration protocol, if a child has difficulty decoding words, inability to accurately read the words in the passages would likely have contributed to the poor reading comprehension outcomes of the majority of the children. That is, limited prompting is unlikely to have been sufficient to maintain fluency and adequate comprehension of the text for those children who made lots of errors and experienced significant difficulties with word reading.

The answer to what contributes to reading comprehension is relatively clear: both language and word reading outcomes. The answer to what contributes to word reading outcomes is more complex. If the field of cochlear implantation is to move forward in assisting children to achieve age-appropriate reading outcomes it is crucial that factors underlying word reading are better understood. Potential factors underlying word reading are explored in the following section.

7.2.2. What is Related to Word Reading Outcomes for Oral Communicating Children Using a Cochlear Implant?

The findings of the present study indicate that the adequacy of language and phonological processing abilities are strongly related to reading outcomes. In children with normal hearing, the phonological processing measures most frequently associated with reading outcomes include phonological awareness and rapid automatized naming (e.g., Allor, 2002; Catts et al., 2001; Cronin & Carver, 1998; Ehri et al., 2001; Manis et al., 2000). In this section the remaining hypotheses relating to an examination of the factors that contribute to word reading are explored. In light of the findings from previous literature it was hypothesised that phonological processing skills would be related to word reading, and that phonological processing skills would be related to vocabulary skills. These hypotheses were broadly found to be true, however the strength of the relationships varied across the different aspects of phonological processing. Therefore the relationships with each aspect of phonological processing will be explored individually. In brief, it is suggested that the specification of phonological representations in the lexicon primarily underlies the relationship of phonological awareness with vocabulary, word reading and polysyllabic word production, whereas the quality and endurance of phonological representations in phonological working memory primarily underlies the relationship between phonological working memory and vocabulary, and that this relationship may have been stronger in participants in the early stages of word learning. The findings also suggest that the quality of phonological representations in working memory and the lexicon are related, and that performance on some measures, such as phonological awareness tasks, may be influenced by both the specification of phonological representations in the lexicon and the capacity of an individual's phonological working memory.

7.2.2.1. Phonological Awareness and Word Reading

Phonological awareness has been directly related to word reading in children with normal hearing. Specifically, those children who have good explicit awareness of the sound structure of language subsequently have better word reading (Ehri et al., 2001; Gillon, 2004; Muter et al., 2004; Wagner et al., 1997). The findings from the present investigation confirm this observation for children using a cochlear implant, as the participants with better phonological awareness abilities had better word reading outcomes.

In the field of cochlear implantation, there have only been a small number of studies that have previously investigated a possible relationship between phonological awareness abilities and reading in children using a cochlear implant. The findings about the strength of the relationship have been somewhat mixed. Geers (2003) found a significant but weak correlation between rhyme awareness and reading in children using a cochlear implant and either TC or OC. Geers concluded that her participants used both orthographic and phonological coding strategies to determine rhyming pairs. Fagan et al. (2007) found a strong relationship between reading and phonological awareness in a small group of oral communicating children using a cochlear implant. Together, these studies and the findings from the current study provide evidence that children using a cochlear implant and oral communication exhibit a relationship between word reading and phonological awareness similar to children with normal hearing. Moreover, the current study indicates that similar to children with normal hearing, children using a cochlear implant can use both orthographic and phonological strategies for word reading.

The current study also found that phonological awareness is strongly correlated with language, phonological working memory, phonological retrieval and polysyllabic word production. Table 7-2 and the scatter plot graphs (Appendix K) highlight the strong relationships between phonological awareness and these variables.

On the surface the tasks that comprise the individual variables that are significantly correlated, are very different. For example the language tasks involve assessment of language form and content, and include sentence level tasks such as formulating sentences and following directions; the speech production tasks require the children to look at pictures and pronounce the name of the picture; the word reading tasks require the children to read aloud written words, and the phonological awareness tasks are specific to the awareness of, and ability to manipulate sounds and include many specific tasks such as phoneme deletion and phoneme blending. The obvious question that arises from the research findings is 'What is the factor that underlies the relationships between measures of phonological processing, production of polysyllabic words, spoken language and reading?' Could this commonality be the specification of phonological representations in long-term memory?

The concept of phonological representations is a theoretical notion and it is difficult to directly measure because of its perceived centrality to speech processing any deficits in input or output skills would affect the measure. Munson (2006, p.578) comments on the abstract notion of phonological representations stating, "Representations themselves are latent variables. We can never see them, we can only posit them as explanations for the sensitivity that people have to variation and consistency in the speech signal in different tasks". The current study has used a number of measures that supposedly utilize the theoretical construct of phonological representations to posit the indicative strength of the underlying phonological representations. Thomson, Richardson and Goswami (2005, p.1212) suggest that, for children with normal hearing, phonological awareness "provides an index of the representational adequacy of a child's long-term phonological representations". This is espoused by the findings in the current study of strong correlations of phonological awareness with variables that theoretically utilize phonological representations such as production of polysyllabic words and vocabulary.

Correlation analyses do not inform as to causality. In some instances the direction of the relationship might be hypothesised. In this thesis phonological awareness is taken as a measure of the level of specificity of the phonological representations. However, it is possible that the representations also become more specified with increasing explicit awareness of the sounds of language (Gillon, 2000; Gillon, 2005). In addition, the exposure to letters and learning to read words is thought to help reinforce the explicit awareness of phonology (Gillon, 2005). Phonological awareness in children with normal hearing begins to develop before reading. In the present investigation, the phonological awareness abilities of the children were assessed after they had learned or started learning to read at a word level. Therefore it is possible that these relationships are in part bidirectional. Future longitudinal research is required to determine the direction of these relationships.

7.2.2.2. Polysyllabic Word Production, Phonological Awareness and Word Reading

Speech production was also related to phonological awareness and word reading. Polysyllabic word (PSW) production had a stronger relationship with phonological awareness and with word reading than mono- disyllabic words (MDSWs) across reading tasks. Interestingly, while having very few difficulties producing MDSWs the participants had increased difficulties producing PSWs. Such a finding supports the notion that some of these children may experience particular difficulty with specification of phonological representations of longer words in long-term memory. As suggested in chapter 1, PSWs require greater specification in long-term memory (the lexicon) to enable accurate retrieval and production. Fowler and Swainson, (2004, p.268) note that, "longer words - even familiar ones – undoubtedly requires the specification of more phonological details". Sutherland and Dillon (2005) argue that in children with normal hearing, specification of phonological representations underlies reading difficulties that coexist with expressive phonological impairment. If there are only partial or poorly specified phonological representations of words then subsequently retrieval of these words may be partial and production may be poor. In this thesis it is suggested that because the speech production test was a picture naming task rather than a repetition task, and because the participants' production of short words was generally good, that PSW production may have been affected predominantly by the specification of lexical phonological representations. This seems reasonable to suggest as those participants with better PSW production and better phonological awareness were the participants with better word reading skills. Perhaps these children all had better specified underlying phonological representations.

For some children, for a very small number of items (<5%), the name of the stimulus picture had to be provided, either because the children did not recognize the picture, the item was not part of their vocabulary or they were not confident in their retrieval and production of the word. In these few instances phonological working memory constraints may have influenced production of those items. That is PSWs may have been either poorly encoded and/or subject to rapid decay within the phonological working memory. In these instances, because the children were not able to spontaneously produce the word from picture stimuli, support processes such as assistance provided by the redintegration process would likely be limited.

Polysyllabic word production has not previously been included in investigations of phonological processing or reading in children using a cochlear implant. In the current study the inclusion of PSWs in the picture naming tasks was useful in providing additional information about the underyling phonological representations of the participants. Further PSW production was significantly related to both phonological awareness and word reading outcomes. The results indicate that PSWs should be included in picture naming tasks in future research regarding the phonological processing and reading outcomes of children using a cochlear implant.

7.2.2.3. Phonological Awareness, Vocabulary and Word Reading

Phonological awareness and vocabulary were strongly related and there was a common factor that accounted for about 80% of the commonality between them. It is evident in Figure 7-1, that the commonality between language and phonological awareness almost entirely determines word reading outcomes for the participants. In chapter 2 it was hypothesised that the participants with larger vocabularies will have better specified phonological representations and therefore will have better phonological awareness abilities. The lexicon is thought to consist of various representations including semantic and phonological representations (Stackhouse & Wells, 1997). According to the Lexical Restructuring Hypothesis not only do semantic representations refine with vocabulary growth but the phonological representations are also thought to become more specified (Fowler & Swainson, 2004; Walley et al., 2003). The findings of the current study support that a potential source of the commonality between vocabulary and phonological awareness ability is the quality of the underlying lexical phonological representations. That is, those participants with larger vocabularies have better-specified phonological representations, and those participants with better-specified phonological representations have better phonological awareness abilities.

7.2.3. PHONOLOGICAL WORKING MEMORY AND WORD READING

The relationship of phonological working memory to word reading although significant, was not strong. Similarly in studies of children with normal hearing when variables in addition to phonological working memory have been included, phonological working memory has not been found to independently contribute much to reading outcomes (Fowler & Swainson, 2004; Wagner et al., 1997).

In chapter 4 it was discussed that a potential reason for poorer word reading on passage material than word reading on list tasks, was the presence of a greater number of long words that challenge phonological working memory. However, there was no significant relationship between phonological working memory and passage length material, either for word reading or reading comprehension. The majority of the children in the current study had poor phonological working memory with the scores clustered more heavily below the normal range. It is possible that the measure of phonological working memory was not sensitive enough to reflect small differences in the phonological working memory capacities of the participants that may impact word reading. Alternatively it could be that other variables discussed in chapter 4 may better explain the differences in word reading performances on passage and list material rather than length of stimulus words, such as increased cognitive load when required to store information for comprehension, rather than simply accurately producing words.

Phonological working memory may have a role in maintaining phonological codes during the process of phonological recoding in word reading. However the strength of the relationship between phonological working memory and the word reading task that requires phonological recoding (phonemic decoding efficiency), was similar to the strength of the relationship between phonological working memory and sight word reading efficiency – a task that is not dependent on phonological recoding. The similarity between the strength of the correlations may be because phonological working memory ability did not largely affect either phonemic decoding efficiency or sight word reading efficiency.

In a previous study, Dillon and Pisoni (2006) looked at relationships between nonword repetition, lexical diversity and reading in children using a cochlear implant. They found that nonword repetition accuracy was moderately significantly correlated to a range of reading measures, with similar partial correlations[23] between nonword reading, and word attack and reading recognition scores, as was found in this research between similar reading measures (i.e., phonological working memory with phonemic decoding efficiency and sight word reading efficiency), even though different tests and scoring methods were used to the current research. However, Dillon and Pisoni found that the relationship between nonword recognition and word reading was mediated by a measure of lexical diversity. With consideration to the findings reported by Dillon and Pisoni, an alternative explanation for the moderate relationship of phonological working memory and word reading in the current study is that the relationship may have been mediated by vocabulary.

In the current study the strong relationships found between measures that utilize phonological representations suggest that specification of the phonological representations underlies these relationships. The weaker correlations between phonological working memory and the other measures including word reading, vocabulary and speech production suggest that phonological working memory abilities are not as dependent on the strength of the lexical phonological representations. This finding indicates that the measures of phonological working memory, such as nonword repetition, required minimal support from the lexicon. However, there is still a significant relationship between phonological working memory and measures that utilize lexical phonological representations. These relationships may reflect that the capacity of the participants' phonological working memory has had an impact on their

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[23] Factors such as age at onset of deafness, IQ and communication mode were partialled out.

ability to learn new vocabulary and therefore refine their phonological representations. This will be discussed in the next section.

7.2.3.1. Phonological Working Memory and Vocabulary

The group results for both vocabulary and phonological working memory tests were poor relative to typically developing children. Although these two variables were significantly correlated, the strength of the relationship relative to other variables studied was not strong. In children with normal hearing, phonological working memory, in particular performance on nonword repetition, has been significantly associated with vocabulary (Gathercole et al., 1997). One explanation for this relationship is that lexical knowledge supports performance on phonological working memory tasks; either through the development of better specified abstract phonological representations with vocabulary development and/or the potential for the process of redintegration to support temporary retention of words in working memory (see Gathercole, 2006). However, if the relationship between phonological working memory and vocabulary was direct, and specification of underlying phonological representations was the key factor in supporting performance on phonological working memory tasks, then the relationship between these variables could be expected to be stronger.

Gathercole (2006), proposed that relationship between phonological working memory and vocabulary is developmental. According to her phonological storage hypothesis, the encoding and endurance of the phonological representations in working memory affects the ability to learn new words. Gathercole (2006, p.522) suggests that in phonological working memory "the quality of the representations…is influenced both by factors operating at perceptual analysis that determine the quality of the phonological representations (e.g., acoustic quality and phonotactic frequency), and by the endurance of these representations over time". The studies reviewed in chapter 2 suggest that children using a cochlear implant are likely to experience encoding difficulties that may affect new word learning. This may happen via two paths. First, the signal that is being encoded is poor because it is passed through the implant processor so it will be harder for the implant user to establish well-specified phonological representations. Second, if the child using a cochlear implant uses more cognitive resources to encode the poor speech signal then fewer resources will be available for retaining the phonological representations in working memory. A poor phonological working memory capacity is likely to make learning new words, particularly long ones more difficult.

The findings of the current study provide support for the phonological storage hypothesis that proposes that phonological working memory capacity is related to vocabulary acquisition. The children in this study all had difficulty with the perception of speech and all experienced a period of auditory deprivation prior to having their hearing loss identified and an appropriate hearing device fitted. The finding of poor phonological working memory capacity is therefore not surprising. If these children expend more of their cognitive resources on encoding the speech signal, capacity for endurance of the phonological representations may be reduced. Gathercole, (2006) reviewed studies of children with normal hearing and found nonword repetition was strongly correlated with vocabulary in preschool children, but the strength of the correlation has be found to decreased with increasing age. In the current study the relationship found between phonological working memory and vocabulary was weaker compared with the relationships between phonological working memory and other measures utilizing lexical phonological representations. This suggests that phonological working memory limitations, both encoding and endurance may have influenced the participants' vocabulary acquisition particularly in the early stages of word learning. If children expend more resources encoding the speech signal then they may have fewer resources for the temporary storage of representations. If temporary representations are decayed (a situation most likely for longer words) before establishment in the lexicon then many more exposures to the word may be needed before the word is learned – that is, stored in the lexicon with semantic and phonological representations. Once vocabulary begins to grow specification of phonological representations within the lexicon as well as opportunities for multiple exposures to words[24] may diminish the influence of working memory constraints on vocabulary growth.

Phonological working memory was moderately correlated with the sentence level measure of speech perception (BKB words). Rvachew and Grawburg (2006, p. 76) state that, "*Speech perception* is the process of transforming a continuously changing acoustic signal into discrete linguistic units". This definition suggests that speech perception ability theoretically should influence encoding ability and underlie other measures of phonological processing such as phonological working memory. While correlation analyses do not inform as to the direction of the relationship, it is suggested that performance on the BKB words sentence test is more likely to be affected by phonological working memory constraints than the reverse because of the construction of the speech perception task; participants needed to retain the sentences in phonological working memory before repeating the sentence. In chapter 5 limitations of the speech perception tests used in the current study were discussed, specifically with regards to the validity and reliability of the test instruments, and the influences of speech production, phonological working memory and language skills on performance.

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[24] Multiple repetitions of words are likely to have been given to the children in this study who have attended structured AVT sessions.

It is also worth noting the speech perception tests were not standardised (in contrast with many of the test instruments used in this study), and so the percentage scores did not take into account differences in the varying ages of the participants. In this study the single word speech perception measure was not correlated with any of the phonological processing measures. It is possible that these issues (particularly the validity and reliability issues in the CNC words test) account for the lack a relationship with the other measures.

There was a significant relationship between PSW production and phonological working memory, but no relationship of MDSW production with working memory. The capacity of the phonological working memory is stressed with increasing word length. Therefore, the difficulty the children had in efficiently retrieving and correctly producing longer words may be partially the result of a compromised phonological working memory limiting encoding of these words in long-term memory at a younger age.

While the data from the current study suggest that phonological working memory capacity is likely to have influenced ease of new word learning and vocabulary development, future research that tracks the children's progress longitudinally is required to determine the direction of the relationship between phonological working memory and vocabulary in children using a cochlear implant.

7.2.3.2. Phonological Retrieval and Word Reading

Phonological retrieval ability using rapid automatized naming tasks has not previously been reported in oral communicating children using a cochlear implant. In children with normal hearing, performance on rapid automatized naming tasks has been related to word reading performance (Manis et al., 2000; Wagner et al., 1997; Wolf, 1991). Performance on the rapid automatized naming task was related to word reading outcomes. The strength of the relationship varied across the different measures of word reading but was strongest with phonemic decoding efficiency. It appears that quicker retrieval and production of words from picture stimuli is associated with word reading, but that this association is not strong. The exception to this was phonemic decoding efficiency, which was strongly correlated with rapid automatized naming.

There have been different views in the literature as to whether the relationship of rapid automatized naming and word reading reflects common phonological abilities (Griffiths & Snowling, 2001; Swan & Goswami, 1997b; Wagner et al., 1999), or more general abilities associated with word reading such as timing mechanisms (Cronin & Carver, 1998; Manis et al., 2000; Wolf et al., 2000). In the current study, the rapid automatized naming outcomes of the participants were generally better than outcomes for phonological working memory and phonological awareness (see chapter 6), and the stronger relationship with phonemic decoding efficiency, a timed word list task, suggests another factor related to timing may partially underlie the relationship of rapid automatized naming with word reading. However, the significant relationships between rapid automatized naming and phonological working memory and phonological awareness suggest that the contribution of underlying phonological representations to performance on rapid automatized naming tasks should not be entirely dismissed. Children with well-specified phonological representations are more likely to retrieve phonological information from visual stimuli quicker than children with poorly specified representations. The results reported in chapter 6 indicate that the majority of these children do not have a phonological retrieval deficit. However those children who are able to quickly name common words, reflecting quicker phonological retrieval, tend to have better word reading outcomes.

7.3. Conclusion

This research was motivated to explore the premise that children with a significant hearing loss who are given increased access to sound via a cochlear implant and who use a communication approach based on the development of language via listening will have better skills processing phonological information resulting in improved speech, language and reading skills than have been traditionally achieved by children who have a profound hearing loss. The results of the current study support this premise. The children in this research, although profoundly deaf, are able to employ a phonological route for spoken language and written word processing. The very strong correlations between skills utilizing phonological information highlight the importance of well-specified phonological representations to outcomes for these children.

The relationships between speech, language and reading outcome measures for children using a cochlear implant is extremely complex. A strength of the present study is that it measured a range of skills in each outcome area so that a more complete picture of level of functioning and relationships between skills is achieved. The discussion has focused on relating the results of these measures of very different skills, to each other, and to reading, concluding that reading comprehension outcomes are primarily a product of word reading and language abilities. Word reading is related to a number of factors, most strongly language and phonological awareness. The metalinguistic aspect of phonological awareness is important for reading, but so too is the specification of the phonological representations, which may partially determine performance on vocabulary, phonological awareness, speech production, rapid automatized naming and possibly phonological working memory tasks.

While it is encouraging that a number of the children in the present study have reading levels commensurate with their school peers, others are still well below the level of their peers. This research has provided information that suggests that a good language base and good word reading skills are essential for ascertaining meaning from written text. Further the relationships have shown that the better the child's phonological processing, in particular their phonological awareness skills, generally the better the language and word reading skills. This information can be used to guide future research. This research has highlighted that the broader language skills of the children using a cochlear implant are significantly poorer than their hearing peers, and have contributed to poor reading comprehension outcomes. Importantly future research and intervention needs to look at best practice for strengthening both phonological processing and broader language skills at a young age to prevent later reading comprehension difficulties. To help direct the sagacious use of resources in future research, the next chapter considers some of the strengths and limitations of the research documented in this thesis.

Chapter 8. Conclusion: Strengths, Limitations and Concluding Remarks

"We cannot assume that simply because deaf children with cochlear implants are in mainstream classrooms, they learn just like hearing children. Nor can we assume that when children with implants are in separate classrooms, they learn just like other deaf children. Only when we fully understand how children with implants think and learn will we be able to adjust our instructional methods to match both their strengths and their needs".

Marschark et al. (2007, p.280)

8.1. Conclusion

I began this thesis reflecting on my experience as a speech-language pathologist working with children using a cochlear implant. In my experience, I had encountered children with a significant hearing loss who struggled to learn to read, and often failed to achieve the same reading outcomes as their peers with normal hearing. Some children I saw were great readers, their speech was intelligible and their language was good. Other children who struggled to read also did not have a good a grasp on language. They also struggled to clearly pronounce polysyllabic words like 'stethoscope', 'ambulance' and 'zucchini'. My fascination with the reading, speech and language abilities of children using a cochlear implant was the impetus behind the research documented in this thesis. It represents a journey that began with a simple clinical observation culminating in a comprehensive in-depth study of the reading, language, speech and phonological processing abilities of oral communicating children using a cochlear implant, and the relationships between the variables with regards to reading outcomes. A number of key findings emerged. Based on the overall results of the group of 47 children, when compared to the norms for their peers with normal hearing:

- word reading on average was good (i.e. within the normal range), while reading comprehension was poorer;
- language skills were poor;
- speech production for polysyllabic words was poor relative to mono-disyllabic words;
- phonological retrieval was good, while phonological working memory was poor. Phonological awareness was good for only half of the participants.

Chapter 7 explored the relationships among reading, language, speech and phonological processing. It was found that language and word reading ability were most strongly related to reading comprehension. In addition phonological awareness and language were most strongly related to word reading. It was suggested that because children with stronger reading ability had stronger language skills and phonological processing abilities, development of well-specified phonological representations might underlie the relationships.

The key findings of this research indicate that if children using a cochlear implant are to achieve adequate reading outcomes they need to be equipped with strong phonological processing and language skills. Best practices for promoting strong phonological processing and language abilities and looking into how these children learn will be for future research to investigate. However, the current findings, together with the body of literature about successful intervention practices in children with normal hearing, have implications for what might be included in educational practices for children using a cochlear implant. The following considers some of the strengths and limitations of this research.

8.1.1. Strengths and Limitations

- Participant Group
    - Homogeneity of communication mode of participants

One of the strengths of this research is that variability in the characteristics of participants known to influence outcomes was reduced. The children communicated orally, attend mainstream schools, were implanted predominantly between 1 to 3 years of age, participated in AVT in the period prior to and following cochlear implantation and used recent cochlear implant technology. Although larger than some studies in the field of cochlear implantation, controlling for variability in participant characteristics meant that the number of participants limited the choices for analysing the results. Some statistical procedures such as multiple linear regression analyses and structural equation modelling that could potentially further inform as to uniqueness of the different variables' contribution to reading outcomes and direction of the relationships were considered, but found to be unsuitable analyses with the present data because of the highly correlated variables and the relatively small participant numbers. The inclusion of a greater number of participants while still looking at a broad range of outcomes in future research alongside longitudinal research may enable a more definitive determination as to the direction of relationships among the variables studied.

- Age of implantation

The youngest child to receive a cochlear implant in this study was 14 months of age and half of the children received a cochlear implant before 2.75 years. While just a few years ago implantation under 5 years of age was said to be *early* (Geers, 2003), the introduction of universal newborn hearing screening in many countries (Dettman et al., 2007; Wake, 2002), has resulted in many more children with a significant hearing loss receiving a cochlear implant before 12 months of age (Dettman et al., 2007). In children with normal hearing exposure to spoken language begins from birth if not in-utero (Moon & Fifer, 2000), and by 9 months many children demonstrate the beginnings of a receptive vocabulary and by 12 months the beginnings of an expressive vocabulary (Pence & Justice, 2008).

The children with a profound hearing loss in this study typically received a cochlear implant and therefore access to all the sounds of speech at around 3 years of age. This means that most of the participants did not receive complete access to spoken language during the sensitive early years of language development; an age at which their peers with normal hearing would be using complex sentences with embedded clauses (Pence & Justice, 2008). Most of the children in this study were only beginning to hear all the sounds of speech while their hearing peers were going through a stage of fast language acquisition.

Studies of children with a significant hearing loss receiving a cochlear implant and thereby exposure to spoken language at varying ages clearly shows increased language proficiency given early exposure (e.g., Connor et al., 2006; Connor & Zwolan, 2004; Dawson et al., 1995; Dettman et al., 2007; Hammes et al., 2002; Kirk et al., 2002a). There is even some evidence to suggest that the first 6 months of age is an important period for stimulation of the auditory pathway and for exposure to language. Yoshinaga and colleagues (1998) found that children whose hearing loss is identified prior to 6 months of age have significantly better language outcomes than children identified after this age.

At a neural level, synaptogenesis, which is driven by an infant's experiences, is most rapid in the first year of life (Pence & Justice, 2008; Sharma et al., 2005). It is likely that even with intervention and an approach that emphasizes the development of language via listening following cochlear implantation, that if complete access to sounds of speech and language stimulation is not provided during the early years the neural connections in the auditory and spoken language areas will not be as dense and interconnected. In children who do not have early exposure to sound the density and organization of the neural networks might be different to those with very early exposure. One recent study has found that children implanted under 12 months of age have significantly better language outcomes than children implanted between 1 and 2 years of age, and moreover that the language outcomes of the early implanted group are age appropriate (Dettman et al., 2007). The speech and reading outcomes and phonological processing abilities of children identified shortly after birth and implanted prior to 12 months of age may therefore be different to the outcomes of the children in the present research implanted over 14 months of age.

- Assessments

A strength of this research is the inclusion of a broad range of variables known to influence reading outcomes. There were 10 different tests with a total of 22 separate tasks administered to the participants, within a limited time[25]. One skill area not assessed was IQ. In children with normal hearing IQ has been used as an inclusionary factor in the definition of dyslexia: Children classified as having *dyslexia* do not have

[25] Refer to chapter 3 regarding difficulties with recruiting participants for additional testing.

low IQ (Catts & Kamhi, 2005) rather phonological deficits have been implicated as underlying reading difficulties (Catts & Kamhi, 2005; Swan & Goswami, 1997b; Wagner et al., 1993). However, *garden-variety* poor readers with low IQ similar to children with dyslexia have also been found to have phonological processing deficits (Swan & Goswami, 1997a; Wagner & Torgesen, 1987) and reported to benefit from phonological processing focused intervention (Hurford et al., 1994). Further, it has been suggested that there are problems with using IQ tests with children who have reading or language difficulties for reasons such as the "overlap with abilities important in reading" (Catts & Kamhi, 2005, p.61). Nevertheless, IQ has been associated with a number of outcome areas in the series of studies by Geers and colleagues (Geers, 2003; Geers et al., 2003a; Geers et al., 2003b; Pisoni & Cleary, 2003). Therefore it is possible that IQ may have also contributed to reading outcomes of the participants in this study, and may be beneficial to consider in future studies of variables relevant to reading outcomes.

A unique strength of this research is that word length was considered in the assessment of the participants' speech production skills. Word length, particularly production of MDSWs versus PSWs has not been considered in the area of cochlear implantation. The children in this research predominantly did well on MDSW production. The inclusion PSWs in the speech production assessment distinguished the children with different speech production abilities, and provided additional information on the strength of the underlying processes, particularly the specification of the underlying phonological representations. However, because the focus of this thesis was on the reading and underlying skills rather than speech production ability, the analysis

[25] Refer to chapter 3 regarding difficulties with recalling participants for additional testing.

of production of words was broad. A fine transcription and analysis of PSWs may have further distinguished the speech production abilities of the participants. Further the speech production test was presented firstly as a picture naming task, however if the child did not give a response, seemingly because they did not know what the picture was, the word was given to the child and their delayed imitation was recorded. The child was told, *It is a X*, then asked: *What is it?* Therefore, although both picture naming and word repetition tasks require adequate post-lexical motor functioning (James, 2006), for some items the task may have reflected the child's phonological encoding and phonological working memory capacity as well as lexical representations. It would be interesting and clinically relevant to compare children's spontaneous versus imitated productions of PSWs, and to consider the potential differences in performance in relation to measures of phonological processing and reading.

8.2. Concluding Remarks

Graham Greene (1940) said "*There is always one moment in childhood when the door opens and lets the future in*" (Pt. I, Ch.1). For children with a significant hearing loss, the moment their cochlear implant is switched on, the door to the world of sound is opened. Historically, children with a significant hearing loss faced an unpromising future as poor readers (Kaderavek & Pakulski, 2007). Children who use a cochlear implant have entered into a different future. The research documented in this thesis, suggests that they can be good readers, however the cochlear implant is no guarantee of this. The research has revealed that phonological processing and language are key foundations for good reading. What remains to be understood is how best to promote the acquisition of these key abilities and how parents and educators can best shape the future for children who use a cochlear implant.

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Appendix A: Information for Parents

The University of Sydney
Faculty of Health Sciences
SCHOOL OF COMMUNICATION SCIENCES AND DISORDERS

THE CHILDREN'S COCHLEAR IMPLANT CENTRE (NSW)
Director: Prof. W.P.R. Gibson MD FRACS FRCS
Telephone & TTY (02) 9817 0011
Facsimile (02) 9817 0033

Information for Parents

Project Title: An investigation of the phonological processing and literacy skills of children using a cochlear implant.

Dear ....

I would like to include .... in a study investigating the phonological processing and literacy skills of children using a cochlear implant. The phonological processing (processing of sounds of a language) and literacy skills of normal hearing children have been widely researched. However, little information is known about these skills in children who use a cochlear implant. Such information could help us to better devise training programs to support the literacy development of children using a cochlear implant.

This study would involve an assessment of your child's reading, spelling skills, and speech sound processing skills, such as discrimination and memory for speech sounds. These skills would be assessed in a similar fashion to your child's annual language assessments. Kylie Rattigan, Speech Pathologist at The Children's Cochlear Implant Centre (CCIC) and my post graduate research student, will carry out the assessment. The tests are those routinely used by professionals such as speech pathologists, and children generally enjoy doing them. However, if your child was to tire or become upset testing would be stopped immediately.

The testing will take approximately 1.5 to 2 hours and would be carried out at CCIC, within one month of their annual language assessment so that the information can also be used in the research analysis. Part of the assessment will be video taped to assist with the accurate recording of your child's responses. These video tapes will be retained by the researcher. The assessment would be arranged at a time convenient for you, including out of work hours to minimise school disruptions. Country families who come to Sydney overnight for their annual assessment may wish to have the research assessment a day before their annual language assessment or on a MAPping visit.

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Appendix 8: Consent Form

All individual information collected during the study will be treated confidentially and no identifying information will published. Your child's results on the assessments will be reported to you. Professionals working with your child such as teachers or speech pathologists can be sent the information at your written request.

Your child's name was obtained from the CCIC database and if you elect to participate in this study additional information such as your child's educational placement, mode of communication and age of hearing aid fitting will also be obtained from CCIC's existing database of files. Participation in this project is voluntary and you child is permitted to withdraw from the project at any time without penalty or prejudice.

You will be contacted shortly to see if you would like .... to participate in the study and to answer any further questions you may have regarding this.

If you have any questions about this, please do not hesitate to contact Kylie on (02) 9817 0011, or myself on (09) 9351 9447.

Yours Sincerely,

[Redaction]

Professor Vicki Reed
Research Supervisor and Head of School,
School of Communication Sciences and Disorders

The ethical aspects of this study have been approved by The University of Sydney Ethics Committee. If you have any complaints or concerns of an ethical nature about this study, please contact The Manager for Ethics and Biosaftey Administration on (02) 9351 4811.

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Appendix B: Consent Form

The University of Sydney
Faculty of Health Sciences

SCHOOL OF COMMUNICATION SCIENCES AND DISORDERS

THE CHILDREN'S COCHLEAR IMPLANT CENTRE (NSW)

Director: Prof. W.P.R. Gibson MD FRACS FRCS

Telephone & TTY (02) 9817 0011
Facsimile (02) 9817 0033

LETTER OF CONSENT

Project Title: An investigation of the phonological processing and literacy skills of children using a cochlear implant.

I have read the letter outlining the above study. I understand that participation in this project is voluntary and that I may withdraw my child from the study at any time without penalty or prejudice.

I .... give consent for my child

....

to participate in the phonological processing and literacy study. I understand that as part of this study my child's assessment will be video taped.

Signed:.............................. Date:..................
Parent/Guardian

Witness:____________________ Date:__________

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Appendix C: Principles of Auditory-Verbal Practice

1. To detect hearing impairment as early as possible through screening programs, ideally in the newborn nursery and throughout childhood.

2. To pursue prompt and vigorous medical and audiological management, including selection, modification, and maintenance of appropriate hearing aids, cochlear implants or other sensory aids.

3. To guide, counsel, and support parents and caregivers as the primary models for spoken language through listening and to help them understand the impact of deafness and impaired hearing on the entire family.

4. To help children integrate listening into their development of communication and social skills.

5. To support children's Auditory-Verbal development through one-to-one teaching.

6. To help children to monitor their own voices and the voices of others in order to enhance the intelligibility of their spoken language.

7. To use developmental patterns of listening, language, speech, and cognition to stimulate natural communication.

8. To continually assess and evaluate children's development in the above areas and, through diagnostic intervention, modify the program when needed.

9. To provide support services to facilitate children's educational and social inclusion in regular education classes.

Retrieved 4/11/2002 from: http://www.auditory-verbal.org.

Appendix D: Number of Participants to Complete Tests

Name of Test[1]	*Number of Participants*
NEALE-3	45
TOWRE	46
QUIL	40
CTOPP	47
ACAP Adapted	46
CELF (3rd and Preschool Editions)	46
PPVT-3	47
GASP	47
CNC Words	47
BKB Sentences	47

[1] Neale-3 - Neale Analysis of Reading Ability-Revised (Neale 3rd Edition, 1999); TOWRE -Test of Word Reading Efficiency (Wagner, Torgesen & Rashotte, 1999); QUIL - Queensland Inventory of Literacy (QUIL) (Dodd et al., 1996); CTOPP - Comprehensive Test of Phonological Processing (Wagner, Torgesen & Rashotte, 1999); ACAP Adapted - adapted version of the Assessment of Children's Articulation and Phonology (James, in preparation); PPVT-3 - Peabody Picture Vocabulary Test – 3rd Edition (PPVT-3) (Dunn & Dunn, 1997); CELF-Preschool - Clinical Evaluation of Language Fundamentals Preschool and CELF-3 - Clinical Evaluation of Language Fundamentals – 3rd Edition (Semel et al., 1995); GASP - Glendonald Auditory Speech Perception (Erber, Glendonald, Vic, 1974); CNC words - Consonant-Nucleus-Consonant Word Test (Peterson & Lehiste, 1962); BKB - Bench-Kowal-Bamford Sentences (Bench, Doyle, & Greenwood, 1987).

Appendix E: Psychometric Properties of Tests

Test	*Types of Scores*	*Standardisation*	*Reliability*
1. Neale Analysis of Reading Ability 3rd Edition (Neale-3)	Raw scores, percentile ranks, stanines, performance descriptors, national profile levels and reading ages	**Who**: 1394 students with normal hearing from 116 mainstream schools[2] **Where**: Australian schools **When**: Final school term of 1997	A stable, consistent and accurate test of reading ability High parallel form reliability for accuracy and comprehension measured across year groups (range: 0.81 – 0.98). Lower and greater range of parallel form reliability for rate: 0.69 –0.96. The reliability coefficients for internal consistency were high for both forms across YOS groups and assessment areas (r = 0.85 – 0.96), although lower for comprehension scores of individuals in YOS 1: Form 1 (r = 0.71) and Form 2 (r = 0.81).

[2] The number of schools and students from different states/territories was represented proportionally and a stratified random sampling procedure based on socio-economic status of the schools in Australia was used in the selection of the schools. A number of schools used in the standardisation testing are schools that are attended by the participants of the current research project.

2. Test of Word Reading Efficiency (TOWRE)	Raw scores, subtest standard scores (age and grade based), composite standard scores (mean =100; SD =15)[3]. percentile scores, age equivalents, grade equivalents	**Who**: 1,507 individuals with normal hearing between the ages of six and twenty four years. **Where**: Across 30 states in the USA. **When**: 1997 & 1998	Reliability coefficients for subgroups in the normative sample were between 0.93 and 0.98
3. QUIL	Subtest raw and standard scores (year of schooling based) (mean = 10; SD = 3)	**Who**: 706 students in years 1 to 7 with normal hearing from state primary schools in Brisbane, Australia **Where**: Brisbane, Australia **When**: 1994	Information not available
4. PPVT-3	Raw scores, standard scores, percentile ranks, age equivalents, normal curve equivalents and stanines.	**Who**: 2725 individuals with normal hearing matched proportionately to the USA census data from March 1994 **Where**: USA **When**: 1995 & 1996	Tables of the reliability confidence bands based on the standard errors of measurement (SEM) are provided in the test manual.

[3] Scores between +1 or –1 standard deviation are within the normal range

5. Comprehensive Evaluation of Language Fundamentals (CELF (3 & Preschool Editions)	Raw scores, subtest standard scores (mean = 10; SD = 3), composite scores for expressive language, receptive language and total language (mean = 100; SD = 15)[2].	**Preschool Edition** **Who**: 800 children with normal hearing from USA and was a stratified representation of the US population census (1988) **Where**: USA **When**. 1991	**Preschool Edition:** Reliability coefficients for internal consistency higher for the younger age groups and for the composite scores (range = 0.83 to 0.96; with the exception of age group 6-6 to 6-11 range = 0.73 to 0.86). SEM scores low (0.8 – 2.5) enable confidence in the reliability of the obtained score. Test-retest stability coefficients provided for a sample of 57 children were high for the composite scores (range = 0.87 to 0.97) and for all subtests (range = 0.75 to 0.92), with the exception of sentence structure (range = 0.60 to 0.64).
		3rd Edition **Who**: 2,450 individuals aged 6 – 21 years with normal hearing from USA and was a stratified representation of the US population census (1988) **Where**: USA **When**. 1994 - 1995	**3rd Edition** Reliability coefficients for internal consistency higher for the composite scores (range = 0.83 to 0.95 for composite scores across age groups). SEM scores low (.90 – 2.0 for subtest scores across age groups) enable confidence in the reliability of the

			obtained score. Test-retest stability coefficients provided for a sample of 152 children were high for the composite scores (range = 0.80 to 0.94).
6. Comprehensive Test of Phonological Processing (CTOPP)	Raw scores, age and grade equivalents, percentiles and standard scores for the subtest scores (mean = 10; SD = 3) and composite scores (mean = 100; SD = 15)[2].	**Who**: 1656 individuals with normal hearing representative of the national demographic characteristics **Where**: Across 30 states in the USA. **When**: 1997 & 1998	Test-retest stability reliability coefficients for composite and subtest scores ranged between 0.70 and 0.94. Inter-scorer reliability coefficients subtest and composite scores across test versions were predominantly 0.99 with a range of 0.95 – 0.99

Appendix F: Assignment to Year of Schooling Level[4]

Age Range	*YOS*
5.08 – 6.08	1
6.09 – 7.08	2
7.09 – 8.08	3
8.09 – 9.08	4
9.09 – 10.08	5
10.09 – 11.08	6
11.09 – 12.08	7

[4] The standardisation of the QUIL was done in Brisbane schools in third term; July to September. The mean age for each grade is stated in the QUIL manual (p.29), and this was used to determine the year of schooling (YOS) level to use for the research group. For example Year 1 mean age = 6.3 therefore for participants 5.08 to 6.08 Grade 1 (YOS = 1) norms were used, and participants 6 years 9 months to 7 years 8 months were assigned to YOS 2. One participant in this study attended school and was able to do the Neale-3, but was only 5;6 years at the time of testing. This participant was compared to the norm tables for YOS 1, which was their school peers.

Appendix G: Demographic and Implant Characteristics of Participants for Each Test (mean, median, range, standard deviation)

		Overall *n = 47*	*Neale –3* *n = 45*	*TOWRE* *n = 46*	*TOWRE* *n = 43*	*QUIL* *n = 40*
Age at reading assessment (years)	**Mean**	8.75	8.90	8.83	9.05	9.23
	Median	8.75	8.92	8.87	9.08	9.17
	Range	5.33 - 12.50	5.50 - 12.50	5.50 - 12.50	6.00 – 12.50	5.50 – 12.50
	Standard Deviation	2.05	1.96	2.00	1.87	1.82
Age at language assessment (years)	**Mean**	8.74	8.91	8.82	9.07	9.27
	Median	8.75	8.92	8.83	9.17	9.25
	Range	4.83–12.83	5.25 -12.83	5.17–12.83	6.00 – 12.83	5.17 – 12.83
	Standard Deviation	2.15	2.04	2.10	1.93	1.86
Months between assessments	**Mean**	2.49	2.38	2.41	2.39	2.35
	Median	2.00	2.00	2.00	2.00	2.00
	Range	0 – 10	0 – 10	0 – 10	0 – 10	0 – 10
	Standard Deviation	2.28	2.26	2.25	2.31	2.25
Year of Schooling (YOS)	**Mean**	3.53	3.69	3.61	3.84	4.00
	Median	4.00	4.00	4.00	4.00	4.00
	Range	K – 7	K – 7	K – 7	K – 7	K – 7
	Standard Deviation	2.11	2.00	2.07	1.94	1.92

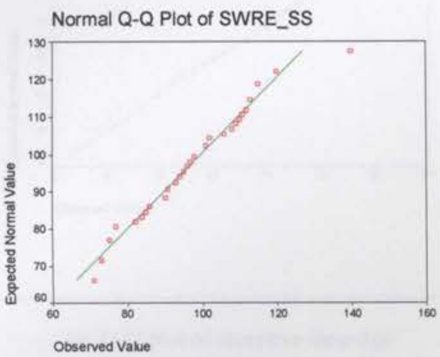
Age at CI (months)	**Mean**	40.13	40.82	40.24	42.95	42.32
	Median	33.00	33.00	32.00	40.00	41.00
	Range	14-97	14-97	14-97	14 – 97	14 – 97
	Standard Deviation	20.13	20.18	20.34	19.92	20.57
Years using CI	**Mean**	5.37	5.46	5.44	5.52	5.66
	Median	4.92	4.92	4.92	4.92	5.41
	Range	2.25-9.83	2.25-9.83	2.25-9.83	2.25 –9.83	2.25- 9.83
	Standard Deviation	1.93	1.91	1.90	1.94	1.92
Age at HA Fitting (months)	**Mean**	16.00	16.31	16.20	16.74	16.32
	Median	14.00	14.00	14.00	14.00	13.5
	Range	2 – 42	2 – 42	2 – 42	2 - 42	2 – 42
	Standard Deviation	10.14	10.24	10.18	10.24	10.54

Appendix H: Speech Production Test: Adapted ACAP, List of Stimulus Words

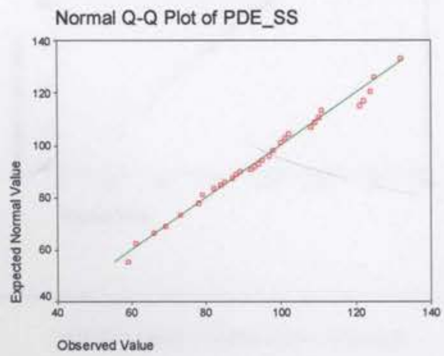
Mono- Disyllabic Words		*Polysyllabic Words*	
jump	zoo	policeman	vegetables
Boy	carrots	octopus	celery
Soap	pumpkin	butterfly	tomato
Blue	ear	broccoli	animals
teeth	lettuce	ambulance	elephant
cage	zebra	stethoscope	helicopter
ice	hear	zucchini	cauliflower
house	giraffe	umbrella	television
spoon	tiger	spaghetti	hippopotamus
play	monkey		

Appendix I: Q-Q Plots of Normal Distribution

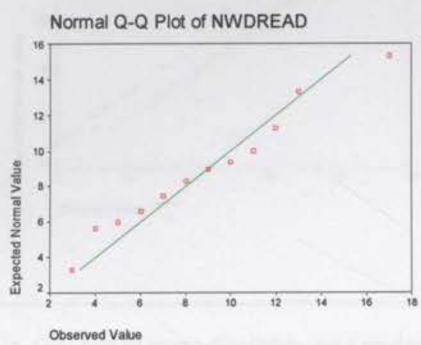
i. Q-Q plot of sight word reading efficiency



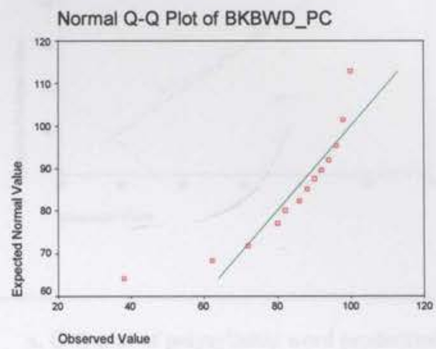
ii. Q-Q plot of phonemic decoding efficiency



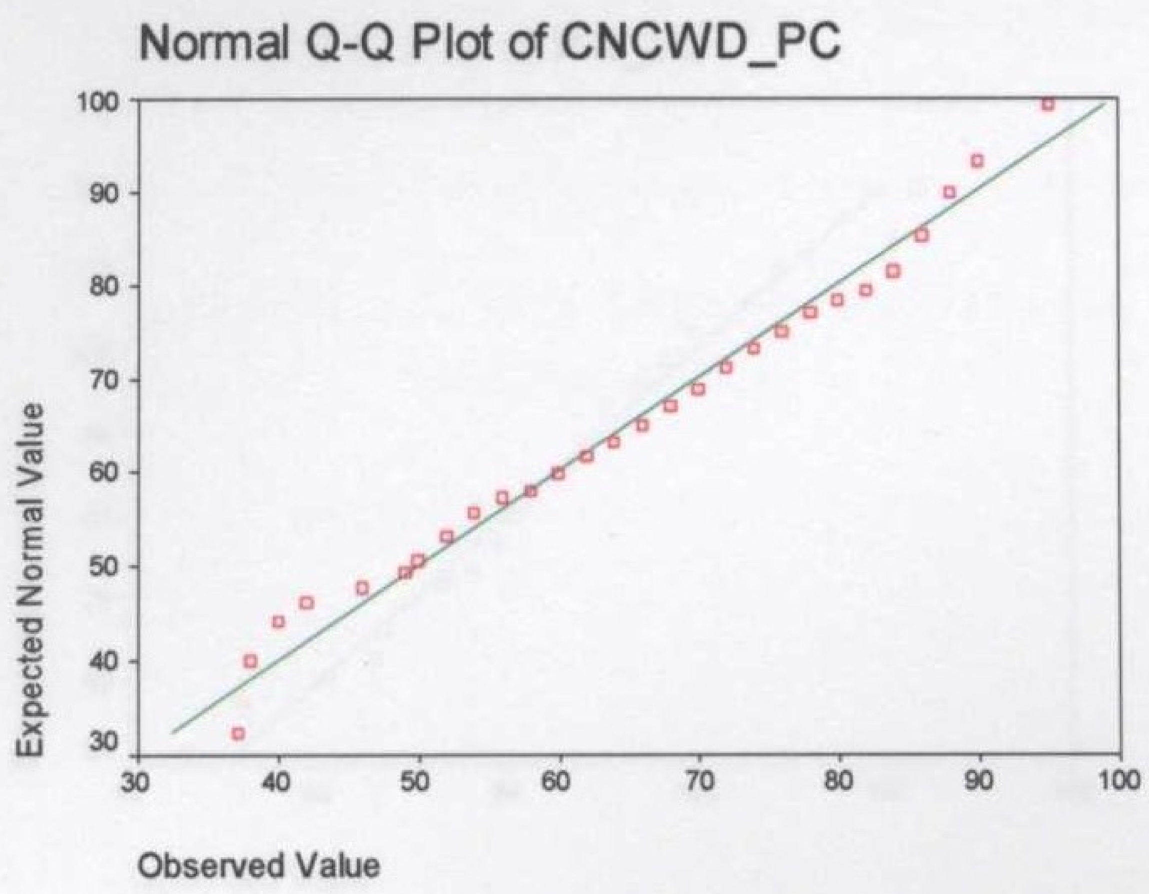
iii. Q-Q plot of nonword reading



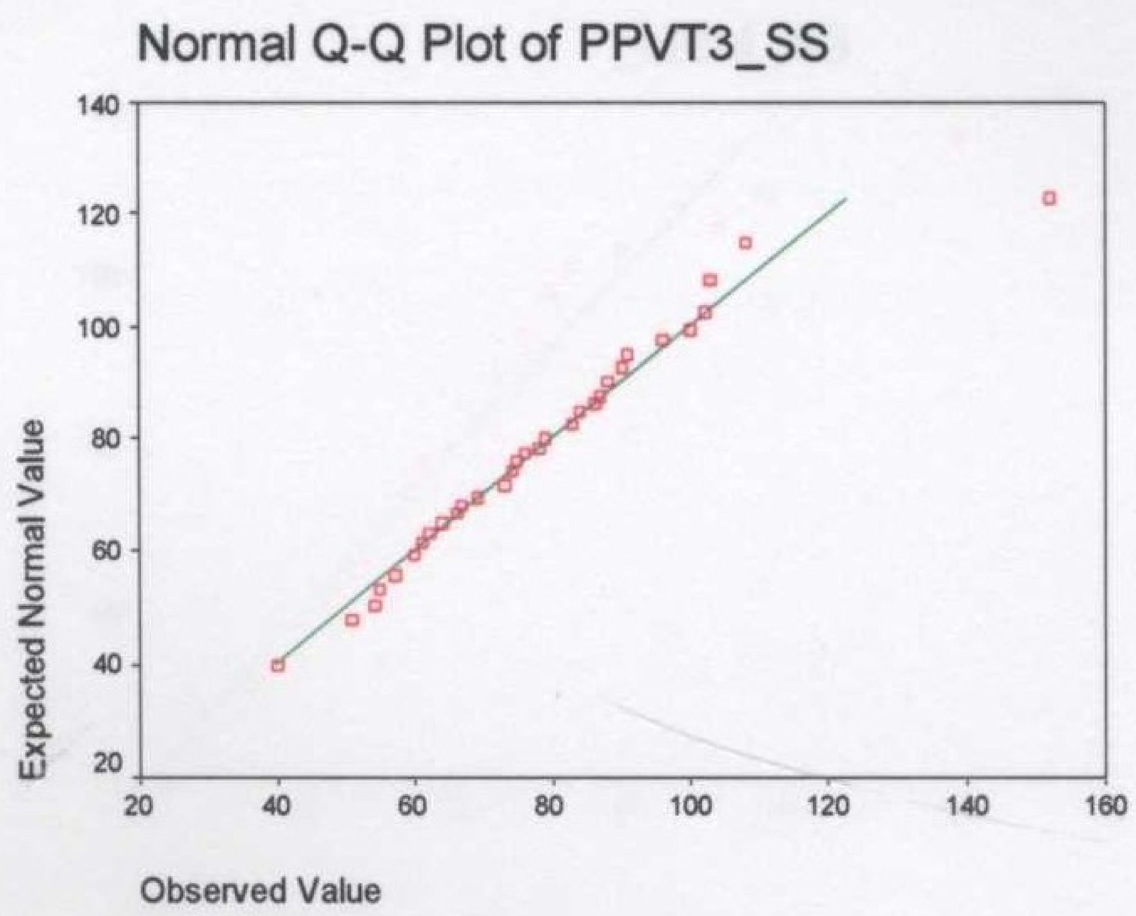
iv. Q-Q plot of BKB words



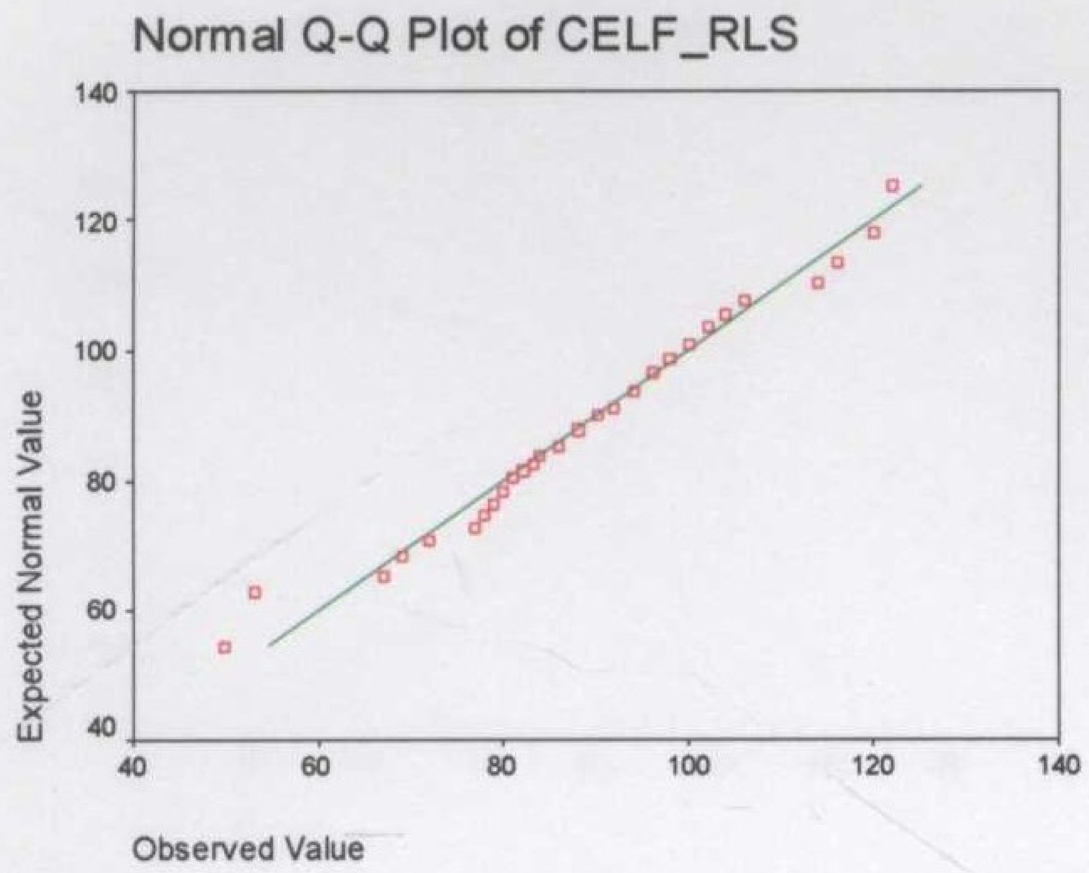
v. Q-Q plot of CNC Words



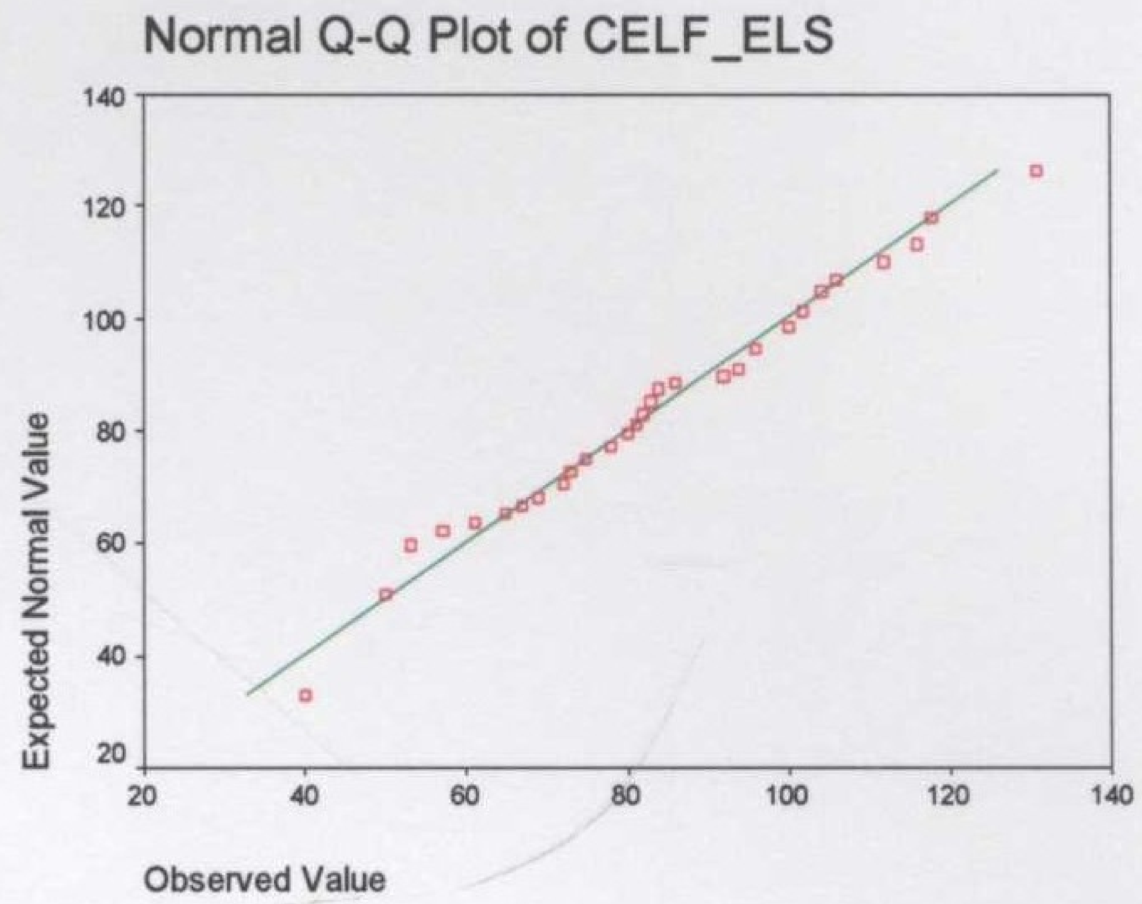
vi. Q-Q plot of receptive vocabulary



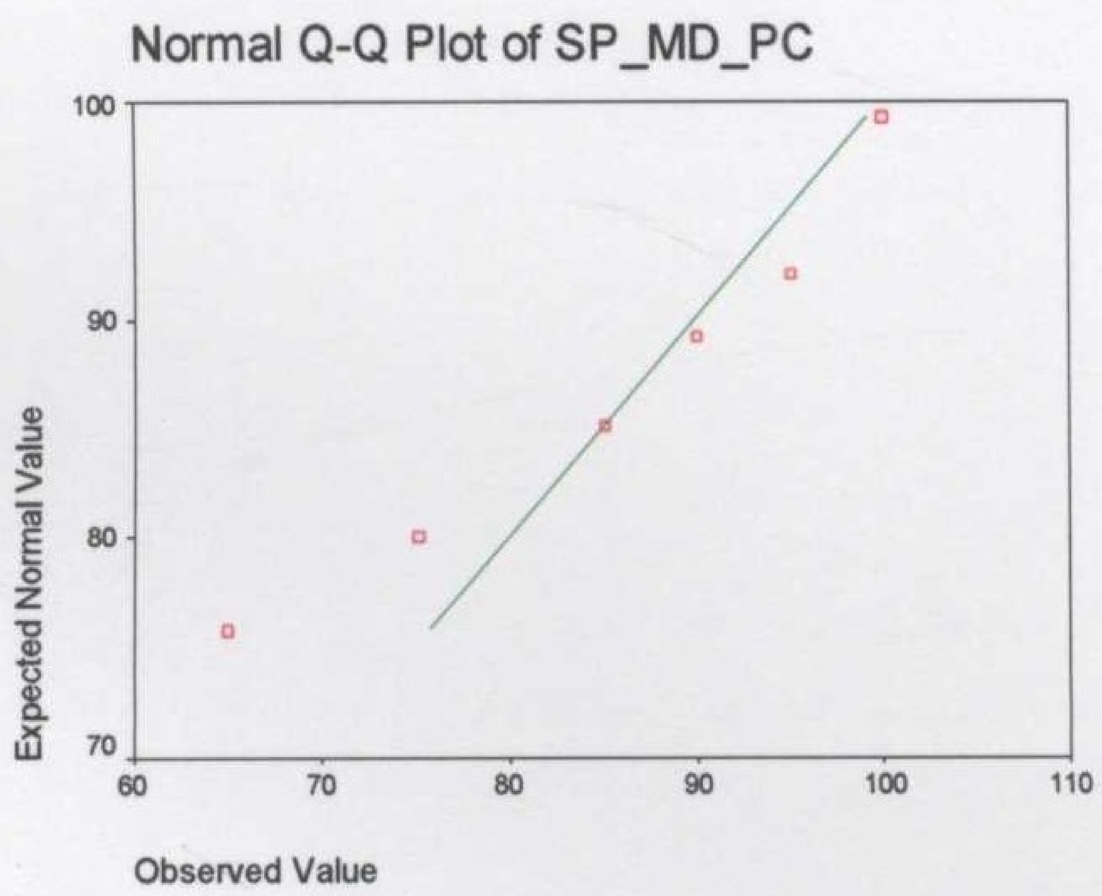
vii. Q-Q plot of receptive language



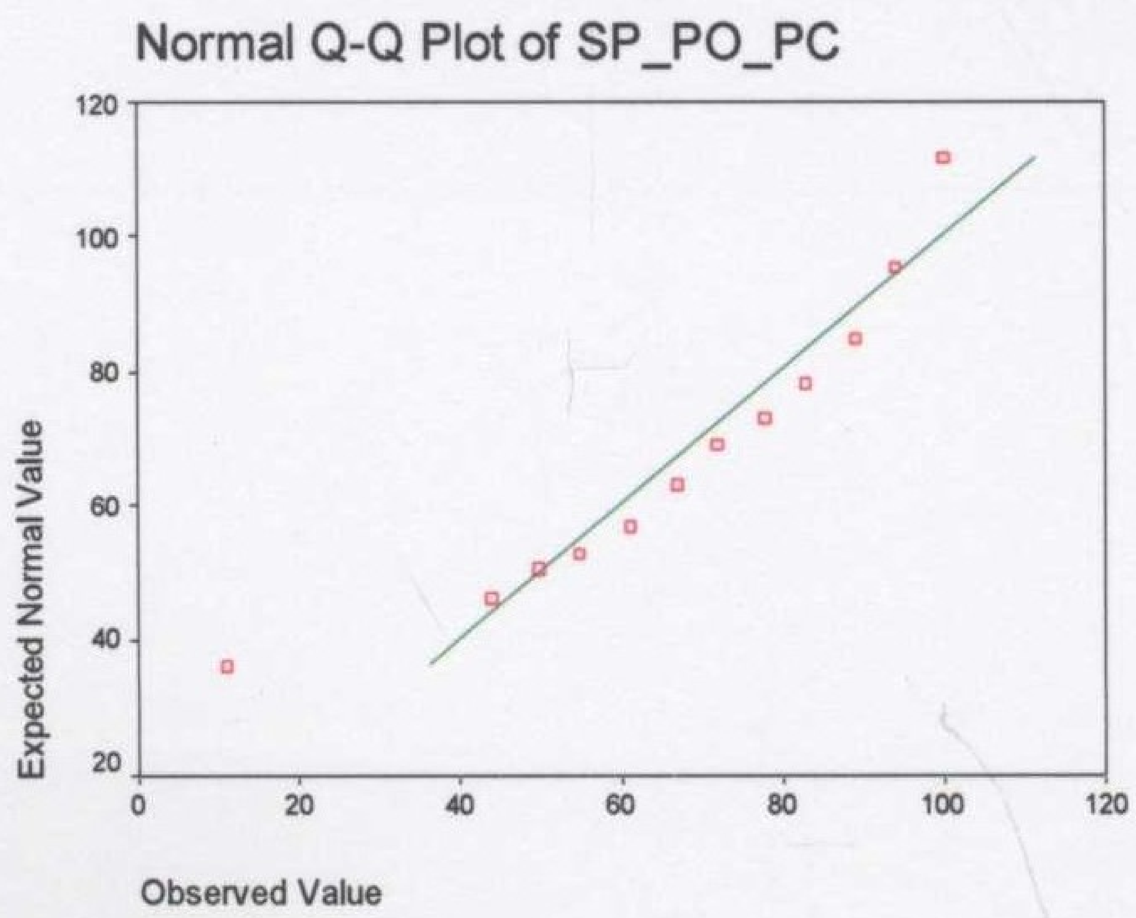
viii. Q-Q plot of expressive language

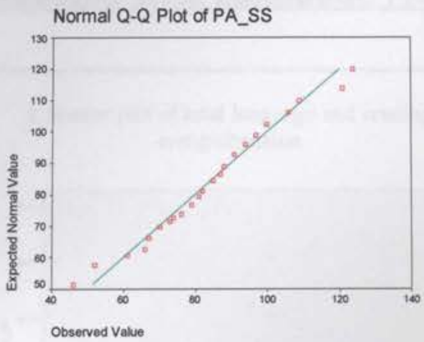
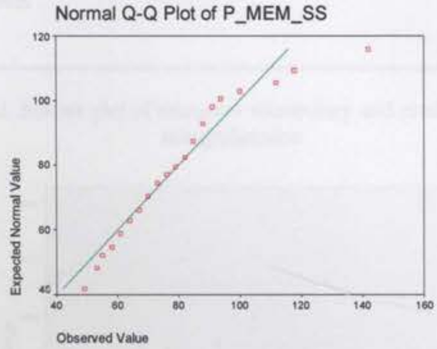
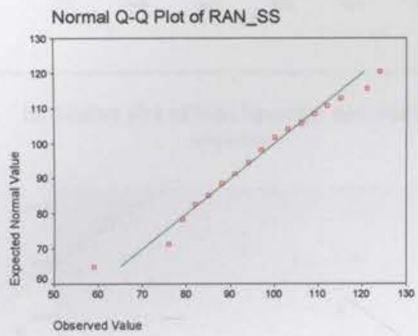


ix. Q-Q plot of mono-disyllabic word production



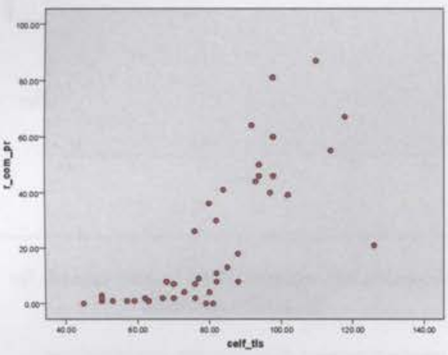
x. Q-Q plot of polysyllabic word production



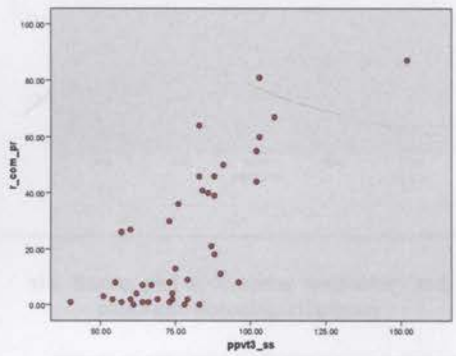
xi. Q-Q plot of phonological awareness	xii. Q-Q plot of phonological working memory
	
xiii. Q-Q plot of phonological retrieval	
	

Appendix J: Scatter Plot Graphs of Relationships of Reading with Language Measures

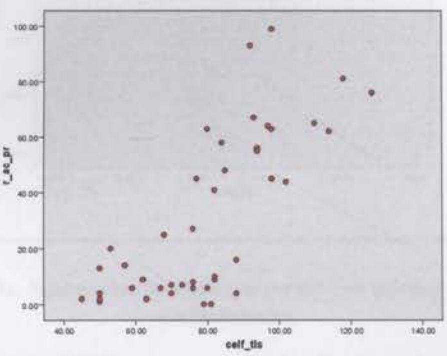
i. Scatter plot of total language and reading comprehension



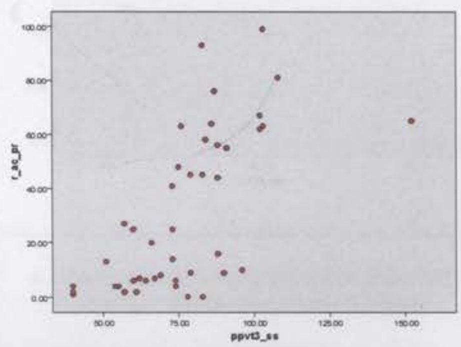
ii. Scatter plot of receptive vocabulary and reading comprehension



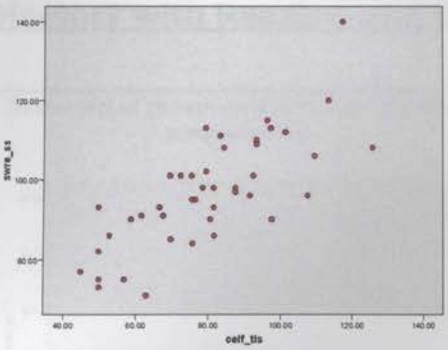
iii. Scatter plot of total language and reading accuracy



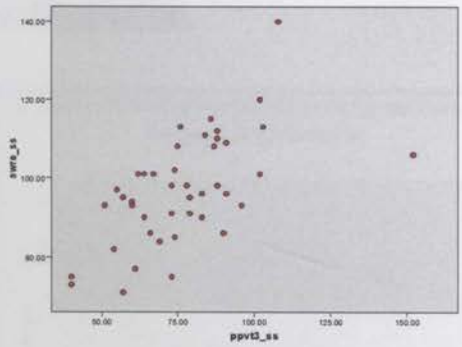
iv. Scatter plot of receptive vocabulary and reading accuracy



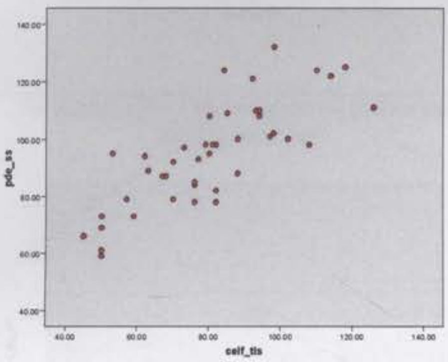
v. Scatter plot of total language and sight word reading efficiency



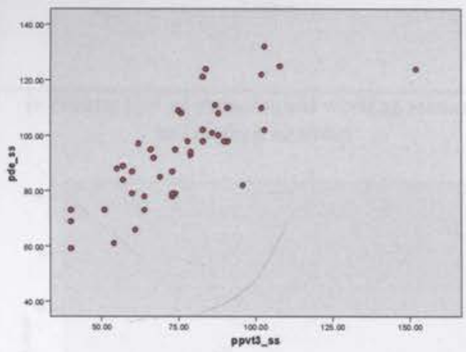
vi. Scatter plot of receptive vocabulary and sight word reading efficiency



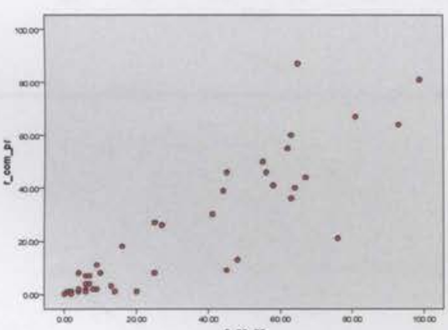
vii. Scatter plot of total language and phonemic decoding efficiency



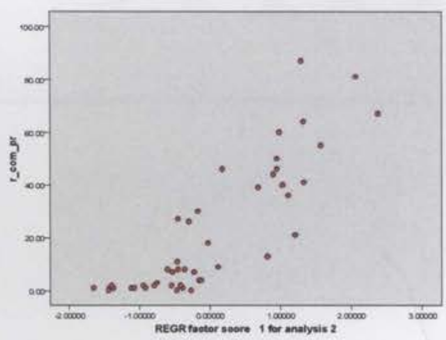
viii. Scatter plot of receptive vocabulary and phonemic decoding efficiency



ix. Scatter plot of reading accuracy and reading comprehension

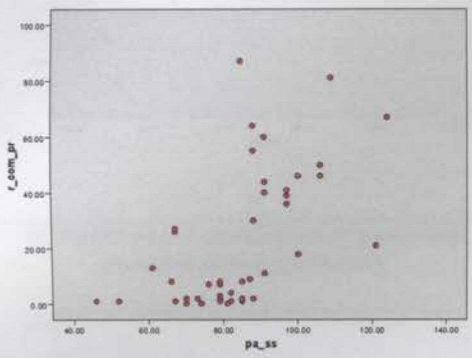


x. Scatter plot of word reading first principal component and reading comprehension

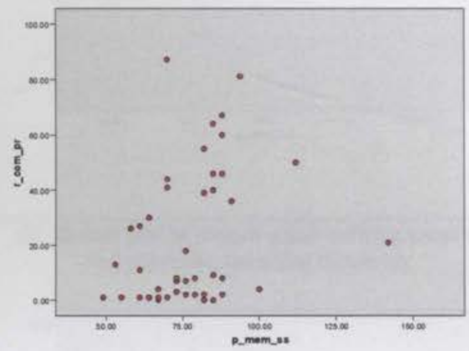


Appendix K: Scatter Plot Graphs of Relationships of Phonological Awareness and Phonological Working Memory with Reading and Other Measures.

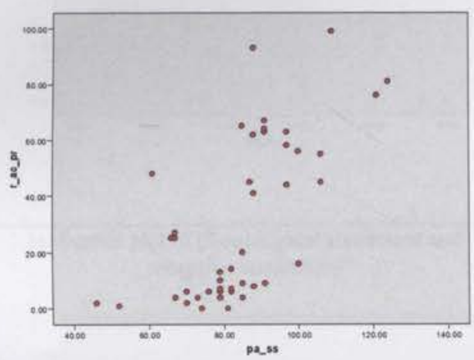
i. Scatter plot of phonological awareness and reading comprehension



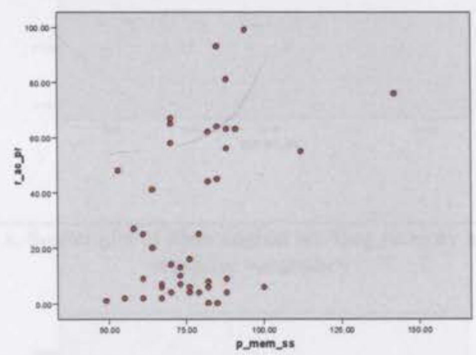
ii. Scatter plot of phonological working memory and reading comprehension



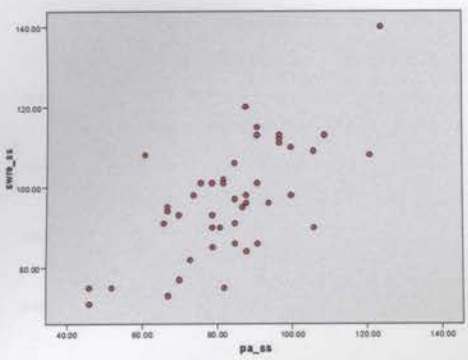
iii. Scatter plot of phonological awareness and reading accuracy



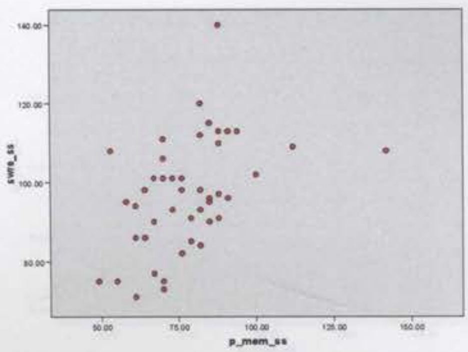
iv. Scatter plot of phonological working memory and reading accuracy



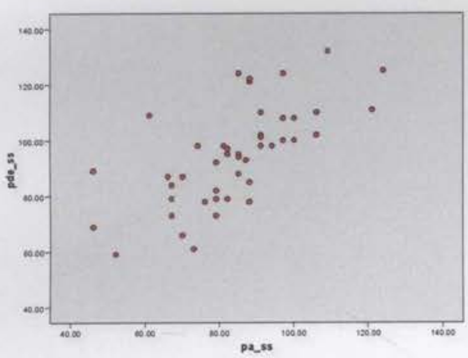
v. Scatter plot of phonological awareness and sight word reading efficiency



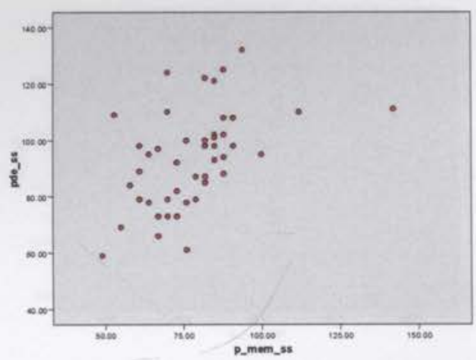
vi. Scatter plot of phonological working memory and sight word reading efficiency



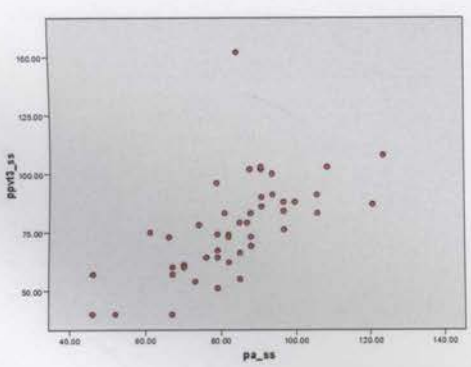
vii. Scatter plot of phonological awareness and phonemic decoding efficiency



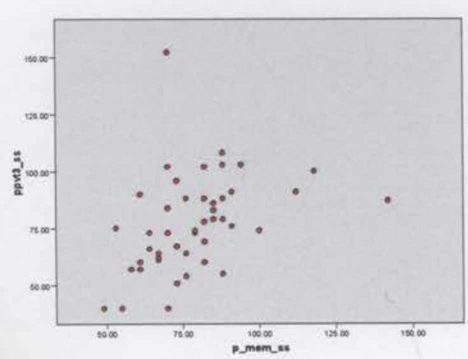
viii. Scatter plot of phonological working memory and phonemic decoding efficiency



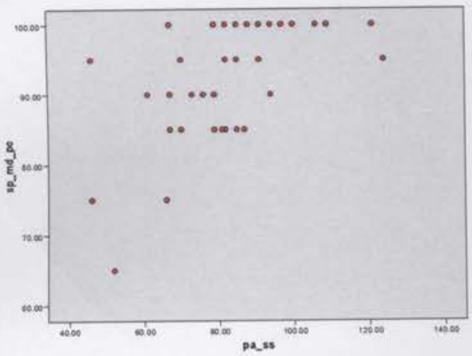
ix. Scatter plot of phonological awareness and receptive vocabulary



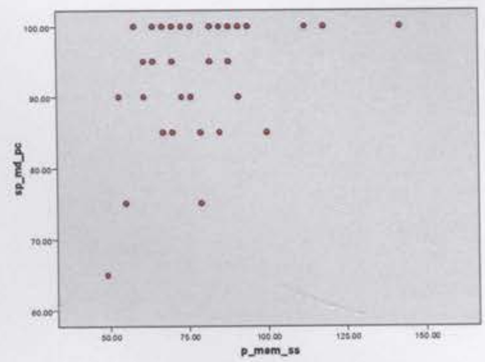
x. Scatter plot of phonological working memory and receptive vocabulary



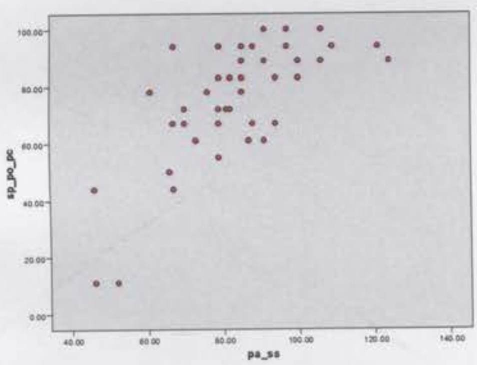
xi. Scatter plot of phonological awareness and mono/disyllabic words



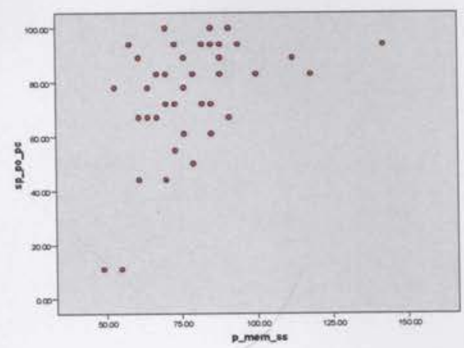
xii. Scatter plot of phonological working memory and mono/disyllabic words



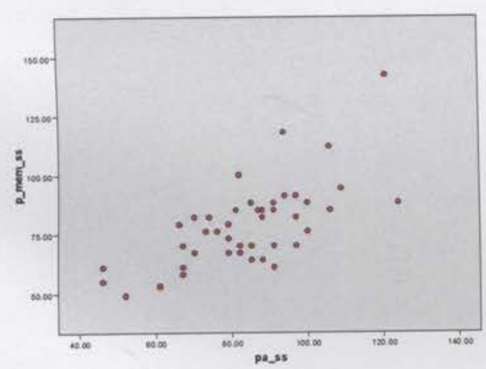
xiii. Scatter plot of phonological awareness and polysyllabic words



xiv. Scatter plot of phonological working memory and polysyllabic words



xv. Scatter plot of phonological awareness and phonological working memory



xvi. Scatter plot of phonological retrieval and phonemic decoding efficiency