Communication outcomes for children who receive a cochlear implant before 2 ½ years of age

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ABSTRACT

Background and aims
This study examined the long-term benefits of cochlear implantation for children who received their first cochlear implant before 2.5 years of age. Using a comprehensive battery of speech perception, speech production and language measures over six years, the study compared communication outcomes for children using cochlear implants and children with normal hearing. The relative influence of age at cochlear implantation and other covariates on outcome measures was examined.

Method
The study design involved the prospective longitudinal evaluation of 32 children with no additional disabilities, who received their first cochlear implant before 2.5 years. Speech perception skills were quantified using the CAP pre-operatively and at one, two and three years’ post-implantation. When the children entered primary/elementary school (five years of age), open-set word testing (CNC) was completed. Speech production was evaluated using the DEAP at school entry. Language was evaluated pre-implantation, at one, two and three years post-implantation, and at school entry using the RI-TLS, PPVT and the CELF or PLS when relevant.

Results
All children in the study developed significant open-set speech perception skills with a group mean monosyllabic word score of 56% and phoneme score of 81%. Speech production skills were delayed compared to normally hearing peers at school entry. Rate of language development for the children (M 1.04) and standard scores (M 86) at school entry were equivalent to hearing peers. Younger age at implantation was found to significantly reduce language delay and was associated with optimum speech production at school entry. There was no significant relationship between age at
implantation and language growth, language standard score at school entry or speech perception. Measures of family participation and child non-verbal IQ were significantly associated with speech perception, speech production and language.

**Conclusion**

Children with cognitive development within the typical range who receive a cochlear implant before 2.5 years of age, can demonstrate speech perception skills sufficient to communicate using audition alone. This level of speech understanding however, does not lead to age appropriate speech production in all cases. In the present study, speech production was delayed compared to hearing peers. Children who receive their first cochlear implant before 2.5 years can demonstrate rates of language acquisition equal to their hearing peers, but may retain a language delay approximately equal to their age at implantation. This data supports the provision of cochlear implants as early as possible to minimise any language delay resulting from an initial period of auditory deprivation.
DECLARATION

This is to certify that:

1. the thesis comprises only my original work towards the PhD except where indicated in the Preface,

2. due acknowledgement has been made in the text to all other material used,

3. the thesis is fewer than 100 000 words in length exclusive of tables, maps, bibliographies and appendices

Jaime Roanne Leigh
22 December 2015
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**ABBREVIATIONS**

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>ABR</td>
<td>Auditory Brainstem Response</td>
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<tr>
<td>AO</td>
<td>Auditory-oral</td>
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<tr>
<td>ANSD</td>
<td>Auditory Neuropathy Spectrum Disorder</td>
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<td>ASSR</td>
<td>Auditory Steady State Response</td>
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<tr>
<td>AV</td>
<td>Auditory-verbal</td>
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<td>AVT</td>
<td>Auditory-verbal therapy</td>
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<td>CAP</td>
<td>Categories of Auditory Performance</td>
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<tr>
<td>CELF</td>
<td>Clinical Evaluation of Language Fundamentals</td>
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<tr>
<td>CI</td>
<td>Cochlear implant</td>
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<tr>
<td>CI-1</td>
<td>First cochlear implant</td>
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<tr>
<td>CI-2</td>
<td>Second cochlear implant</td>
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<tr>
<td>CMV</td>
<td>Cytomegalovirus</td>
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<tr>
<td>CNC</td>
<td>Consonant-Nucleus-Consonant</td>
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<tr>
<td>Comm.</td>
<td>Communication</td>
</tr>
<tr>
<td>dBA</td>
<td>Decibels A-weighted</td>
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<tr>
<td>dBHL</td>
<td>Decibels Hearing Level</td>
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<tr>
<td>DEAP</td>
<td>Diagnostic Evaluation of Articulation and Phonology</td>
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<tr>
<td>EI</td>
<td>Early intervention</td>
</tr>
<tr>
<td>GFTA</td>
<td>Goldman-Fristoe Test of Articulation</td>
</tr>
<tr>
<td>HA</td>
<td>Hearing aid</td>
</tr>
<tr>
<td>ID</td>
<td>Identification</td>
</tr>
<tr>
<td>LVA</td>
<td>Large Vestibular Aqueducts</td>
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<tr>
<td>M</td>
<td>Mean</td>
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<tr>
<td>MAIS</td>
<td>Meaningful Auditory Integration Scale</td>
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<tr>
<td>MCDI</td>
<td>Minnesota Child Developmental Inventory</td>
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<tr>
<td>PLS</td>
<td>Preschool Language Scale</td>
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<tr>
<td>PPVT</td>
<td>Peabody Picture Vocabulary Test</td>
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</table>
PTA  Pure-tone average
RI-TLS Rossetti Infant-Toddler Language Scale
SD  Standard deviation
SES  Socioeconomic status
SS  Standard score
SSEP  Steady-state evoked potential
TB-ABR  Tone-burst auditory brainstem response
TC  Total communication
UNHS  Universal new born hearing screening
VRA  Visual reinforcement audiometry
yrs  Years
1 INTRODUCTION

In early 2005, the Victorian Department of Human Services (Australia) initiated a pre-discharge hearing screening program for all infants born in Melbourne’s major maternity hospitals and those admitted to the Royal Children’s Hospital. It was anticipated that this initiative would result in earlier referral of young children for diagnostic hearing assessment than had occurred in previous years. As a result, these children would also access intervention options (hearing aids and cochlear implants) and early intervention services at a younger age.

Previous research suggests that age at implantation is a significant contributing variable in language and developmental outcomes for children with severe-to-profound hearing loss. The majority of published studies, however, have focused on children implanted over 12 months of age, and with few including significant numbers of children implanted before 12 months of age. Many published studies have also been limited by retrospective study design, short duration of follow up and the description of outcomes has been restricted to one or two aspects of oral language. It is therefore difficult to draw conclusions relating to the specific benefits of implantation at this very young age with the current state of knowledge.

The extent to which a child will use the auditory information provided by a cochlear implant (CI) to develop oral speech and language is affected by factors the child brings to the learning environment, characteristics of the child’s intervention program and characteristics of the family that affect the child’s learning. Numerous studies have attempted to identify the factors that affect speech perception, speech production and language outcomes for children using CIs. Age at cochlear implantation is consistently reported as influencing the outcome for paediatric recipients (Connor, Craig, Raudenbush, Heavner, & Zwolan, 2006; Hammes et al.,
2002; Kirk et al., 2002; Lesinski-Schiedat, Illg, Heermann, Bertram, & Lenarz, 2004; Manrique, Cervera-Paz, Huarte, & Molina, 2004; Nikolopoulos, O'Donoghue, & Archbold, 1999; Schauwers, Gillis, Daemers, De Beukelaer, & Govaerts, 2004; Svirsky, Teoh, & Neuburger, 2004; Waltzman & Cohen, 1998; Waltzman & Roland, 2005; Zwolan et al., 2004). Additional factors frequently reported as influencing outcome for paediatric recipients have included: age at onset of hearing loss (Fryauf-Bertschy, Tyler, Kelsay, & Gantz, 1992; Osberger, Todd, Berry, Robbins, & Miyamoto, 1991; Sarant, Blamey, Dowell, Clark, & Gibson, 2001; Staller, Dowell, Beiter, & Brimacombe, 1991), degree of pre-implant residual hearing (Cowan et al., 1997; Dettman, D'Costa, et al., 2004; Eisenberg, Martinez, Sennaroglu, & Osberger, 2000; Sehgal, Kirk, Svirsky, & Miyamoto, 1998; Zwolan et al., 1997), presence of a developmental delay (Dettman, Fiket, et al., 2004; Dowell, Dettman, et al., 2002; Isaacson, Hasenstab, Wohl, & Williams, 1996; Pyman, Blamey, Lacy, Clark, & Dowell, 2000; Waltzman, Scalchunes, & Cohen, 2000), gender (Geers, Nicholas, & Sedey, 2003), age at identification of hearing loss (Apuzzo & Yoshinaga-Itano, 1995; Markides, 1986; Robinshaw, 1995; White & White, 1987; Yoshinaga-Itano, 2003), educational placement/mode of communication (Connor, Hieber, Arts, & Zwolan, 2000; Kirk et al., 2002) and family characteristics and participation in the intervention program (Bertram & Pad, 1995; Calderon & Low, 1998; Easterbrooks, O'Rourke, & Todd, 2000; Geers & Brenner, 2003; Moeller, 2000; Musselman, Wilson, & Lindsay, 1989).

Central to the argument for early intervention, for children with hearing impairment, are the concepts of auditory deprivation and critical periods for language development. The absence of sound input during the first few years of life can result in irreversible changes to the auditory cortex. The developing auditory system is maximally plastic at birth and this plasticity decreases with age (Ruben & Rapin, 1980). Several studies support the presence of a sensitive period for neural
development that is crucial for spoken language development (Ruben, 1997). This limited window of opportunity, described as the critical period, is maximal in the first 3.5 years of life, decreases dramatically after seven years of age and may be completely closed by 12 years of age (Ponton & Eggermont, 2001; Sharma, Dorman, & Spahr, 2002). These findings have significant implications for the timing and provision of hearing aids (HAs) and CIs for children with pre-lingual hearing impairment.

As the average age of diagnosis of hearing loss has lowered with the initiation of newborn screening around the world, the opportunity to provide children with CIs within the first year of life has increased. In addition to reductions in the age at diagnosis, greater paediatric clinical and surgical experience, advancements in device technology, enhanced awareness of safety and the widespread dissemination of the speech perception capabilities of young children using CIs, have resulted in an increasing number of infants receiving CIs before 12 months of age.

The debate regarding the optimal age of cochlear implantation for children has received significant attention in the literature, with the majority of authors agreeing “the earlier the better”. Age at implantation has been reported to be a significant contributing variable in speech, language and developmental outcomes for children with severe-to-profound hearing loss (Connor et al., 2006; Dowell, Blamey, & Clark, 1995; Hammes et al., 2002; Kileny, Zwolan, & Ashbaugh, 2001; Kirk et al., 2002; Lesinski-Schiedat et al., 2004; Manrique et al., 2004; Nikolopoulos et al., 1999; Niparko et al., 2010; Schauwers et al., 2004; Svirsky et al., 2004; Waltzman & Cohen, 1998; Waltzman & Roland, 2005; Zwolan et al., 2004). Despite this support for early implantation, the majority of children in these studies had significant speech and language delay at the time of implantation; the majority of children worldwide still receive CIs well into the second and third year of life. The benefits of children
receiving CIs before two years of age has now been described in detail (Anderson et al., 2004; Hammes et al., 2002; Hassanzadeh, Farhadi, Daneshi, & Emamdjomeh, 2002; Miyamoto, Hay-McCutcheon, Kirk, Houston, & Bergeson-Dana, 2008; Svirsky et al., 2004; Tos et al., 2000; Waltzman & Cohen, 1998).

To date, only a limited number of published studies have included significant numbers of children implanted by 12 months of age or provided a detailed description of communication outcomes including oral language, speech production and speech perception. Some studies have described the auditory skills (Colletti, Mandala, Zoccante, Shannon, & Colletti, 2011; Colletti et al., 2005; Holt & Svirsky, 2008; Houston & Miyamoto, 2010; Lesinski-Schiedat et al., 2004; Schauwers et al., 2004; Tajudeen, Waltzman, Jethanamest, & Svirsky, 2010; Waltzman & Roland, 2005), speech production (Colletti et al., 2005) and language/vocabulary development (Colletti et al., 2011; Dettman, Pinder, Briggs, Dowell, & Leigh, 2007; Holt & Svirsky, 2008; Houston & Miyamoto, 2010) of children receiving CIs during the first year of life. The majority of these studies have focused on auditory skills as the primary measure of outcome and were limited to a retrospective study design. Although speech perception and/or auditory skill development is a valid measure of CI performance it fails to holistically describe a child’s communicative competence. Language and speech production also play a crucial role in communicative competence and therefore should be considered as part of the overall evaluation of outcome for children using CIs. Of the studies describing language development, a small number have demonstrated increased rates of oral language acquisition in children who receive their CI younger than 12 months compared with children who receive the implant between 12 and 24 months. In contrast other studies have suggested that the differences between the age groups may not be significant and that the language development is related to the time since implant. As a result there is no definitive consensus in the literature as to the specific benefits of implanting
before 2.5 years of age and how these potential benefits may evolve over the preschool years and into early primary/elementary school. The present study will address this question by prospectively assessing three key elements of communicative competence; speech perception, speech production and oral language over a six year period.

It is highly plausible that there are varying sensitive periods for the different aspects of oral communication; speech perception, speech production and language. A few researchers have begun to address this topic when describing the outcomes of children with CIs and further research describing these three aspects of communication on a single cohort of children is warranted.

There is little research that relates specifically to age at identification of children with severe-to-profound hearing loss who proceed with a CI. It is reasonable to assume that an early age of hearing loss identification will result in an earlier age at implantation. In many cases, however, there are additional factors including: medical, audiological, family and/or deaf culture issues that may result in a child not receiving a CI until they are in the second or third year of life. The question therefore remains, is it early identification, early implantation, the combination of both or other covariates that will lead to the optimal outcomes and minimise language delay for severe-to-profoundly hearing impaired children?
2 SUMMARY AND ANALYSIS OF THE RELEVANT LITERATURE

2.1 Auditory deprivation and the critical period for language development

Access to the sounds of speech during the early years of life is crucial for the optimal development of oral speech and language. Children with significant hearing loss, defined as hearing impairment of >40dBHL in both ears (Australian National Hearing Screening Committee, 2001), are at high risk of developing a speech and language delay if the appropriate intervention is not sought as early as possible. Such delays in speech and language skills can have long term implications for employment and quality of life for children with hearing impairment (Cheng et al., 2000; Summerfield & Marshall, 1999).

Central to the argument of “the earlier the better” for intervention for children with hearing impairment are the theories of neural development, auditory deprivation and critical periods for language development.

Development of the auditory cortex typically extends through to the teenage years (Moore & Guan, 2001). The absence of sound input during the first few years of life can result in irreversible changes to the auditory cortex. Ruben and Rapin (1980) have described the developing auditory system as maximally plastic at birth and decreasing with age. Auditory deprivation has been found to cause atrophic changes that bring about extensive degeneration of the central auditory system (Sharma et al., 2002). Much of the evidence described above has been derived from the study of auditory deprivation in a variety of animals. Changes to the central auditory system as a result of auditory deprivation occurs at the level of the spiral ganglion, where there is reduction in cell density (Nordeen, Killackey, & Kitzes, 1983), and extends through to the auditory cortex, where the auditory cortical areas can be reallocated to visual function (Finney, Fine, & Dobkins, 2001). These findings have significant
implications for the timing and provision of HAs and CIs for children with pre-lingual hearing impairment.

Several studies support the presence of a sensitive period for neural development that is crucial for oral language development (Ruben, 1997). This limited window of opportunity, described as the critical period for language development, is maximal in the first 3.5 years of life, decreases dramatically after seven years of age and reported by some as being completely closed by 12 years of age (Ponton & Eggermont, 2001; Sharma et al., 2002).

In the mid-1990s, Ruben (1997) proposed that there may be multiple critical periods relating to the three fundamental elements of language: phonology, semantics and syntax. During these critical periods the auditory system develops the ability to detect and identify different sounds and is partially reliant on the shaping of the central nervous system. At approximately 12 months of age, infants lose their ability to discriminate between, and categorise, phonemes that do not occur within their native language (Werker, Gilbert, Humphrey, & Tees, 1981). Neurophysiological studies indicate a separate neurological site and sensitive period for the development of semantics and syntax (Neville, Mills, & Lawson, 1992). Event related brain potentials in response to words classified as semantic or syntactical revealed adult like responses to semantic words in children as young as four years of age. In contrast, syntactic words elicited responses that changed with age, not acquiring their adult form until 15 to 16 years. This indicates a sensitive period for semantic development, ending before age four and for syntax, a period extending into mid-adolescence.

Although there is widespread support for the presence of the critical period, there are varying reports regarding the upper age limit of this period. There is general agreement that the critical period for oral language development is within the first
five years of life (Kileny, Zwolan, & Ashbaugh, 2001; Manrique et al., 1999; Zwolan et al., 2004). It is during this time children have the greatest potential to learn language.

The critical periods for speech perception, speech production and oral language may vary from one another. Defining the critical periods for these three aspects of oral communication informs the importance of early hearing loss diagnosis and subsequent early implantation for children with severe-to-profound hearing loss. The subsequent sections will describe current knowledge for speech perception, speech production and oral language development.

### 2.2 Development of auditory skills of children using cochlear implants

The development of speech perception skills for children with normal hearing follows a predictable hierarchy from awareness of environmental sounds through to open-set perception performance without the aid of lip-reading. The presence of a hearing loss may disrupt or delay a child’s progression through this hierarchy. If a child’s hearing loss is undiagnosed or not remediated with appropriate amplification the child’s potential to develop auditory skills may be limited.

With the aid of conventional amplification many children with hearing impairment can develop significant open-set speech perception skills. In a study which described the open-set speech perception skills of children with hearing impairment using conventional amplification, Leigh, Dettman, Dowell, and Sarant (2011) reported a significant association between speech perception score and 3-frequency pure-tone average (3FPTA) for a group of 62 children; the greater the degree of hearing loss the poorer the speech perception score. The children with profound hearing loss using conventional amplification had very limited open-set speech perception skills (mean
sentence perception score 34%) compared to their peers with moderate hearing loss (mean sentence perception score 96%).

A decade after the first child received a multichannel CI, Dowell, Blamey, and Clark (1995) reported that 60% of children using CIs achieved significant open-set word and/or sentence perception skills. Large individual differences in performance were noted, even amongst children who used the same speech processing strategy (Tyler, Fryauf-Bertschy, Gantz, Kelsay, & Woodworth, 1997). Speech perception results for children using CIs have steadily improved over time with advances in device hardware and software, surgical techniques and experience with programming sound processors and habilitation.

Studies of children benefiting from more recent technologies and implanted at younger ages have reported further improvements in speech perception skills. In the late 1990s and early 2000s it was suggested that children using CIs performed at a level equivalent to children with a severe hearing loss using conventional HAs (Blamey, Sarant, et al., 2001; Boothroyd, 1997). More recently it has been reported that children who receive their CI before three years of age can achieve speech recognition scores equivalent to those of children with a moderate hearing loss using HAs (Leigh et al., 2011).

Telephone use was initially considered unattainable for children with profound hearing loss given the sophisticated auditory and linguistic skills required to converse effectively. Long-term studies have demonstrated that high proportions of children using CIs (79% and 60%) can converse using the telephone (Beadle et al., 2005; Uziel et al., 2007). These are substantial achievements for children who have been profoundly hearing impaired since birth, and who have developed their auditory processing skills through the degraded signal provided by a CI.
The appropriateness of a speech perception test battery should take into consideration the child’s skill level within the auditory skill hierarchy and also the developmental stage of the individual child. Assessing the speech perception skills of adults and older children is relatively straightforward. Assessment may include closed-set and/or open-set testing; closed-set testing involves the individual listening to a sound or word and pointing to a picture that best represents that sound or word, whereas open-set tests require more sophisticated skills and involves the individual listening to and repeating a sound, word or sentence without context. Young children with age-appropriate cognitive skills who have developed the ability to label sounds, letters or words may be able to complete these types of tasks as young as three years of age (Spencer, Marschark, & Spencer, 2010). With the introduction of newborn hearing screening and the resulting earlier diagnosis of hearing loss, children are presenting for assessment for cochlear implantation at progressively younger ages. This has created a need to assess the perceptual skills of children prior to an age and/or developmental stage in which they can complete formal speech perception testing.

Several methods have been developed to categorize the auditory skills of young children e.g. Categories of Auditory Performance (CAP) (Archbold, Lutman, & Marshall, 1995). Typically these methods are less objective and more reliant on the expertise and judgement of professionals observing behavioural responses in very young children and/or on parent reports of responses to speech sounds and specific familiar words. Despite the potential limitations, reports using these modified forms of speech perception testing in very young children have suggested that speech perception skills can develop rapidly within the first two years of cochlear implantation for children implanted before four years of age (Robbins, Koch, Osberger, Zimmerman-Phillips, & Kishon-Rabin, 2004; Wie, Falkenberg, Tvete, & Tomblin, 2007).
One method for categorizing the speech perception performance of CI recipients, irrespective of their level of functioning, which is widely reported in the literature is the CAP (Archbold et al., 1995). The CAP categorizes auditory skills into eight progressive levels; zero score is defined as ‘no awareness of environmental sounds’ and seven is defined as ‘can use the telephone with a familiar speaker’. Normative data for children with normal hearing using the CAP has been published by Govaerts et al. (2002). One hundred and thirteen normally hearing children assessed at 12, 18, 24, and 30 months of age reached a mean CAP score of two, five, six, and seven, respectively. Early reports using the CAP for children using CIs, with an onset of hearing loss before three years of age, suggested that 91% of children were able to discriminate speech sounds (CAP score of four) one year after implantation and that 81% were able to understand phrases (CAP score of five) by the end of the second year (Archbold et al., 1995). The CAP has more recently been used to describe the auditory skills of children who received a CI in the first few years of life. Colletti et al. (2011) reported that 100% of children implanted before three years of age were able to successfully hold a conversation with a known speaker about a familiar topic (CAP score of seven) by 3.5 years post-implantation.

Once a child reaches a developmental and cognitive age to complete formal speech perception testing, further insight into their auditory skills can be gained through the assessment of open-set speech perception skills. Two large studies, which included over 100 children using CIs, have reported open-set word perception scores of 44% and 53% and open-set sentence perception scores of 57% and 68% (Dowell, Dettman, Blamey, Barker, & Clark, 2002; Geers, Brenner, & Davidson, 2003). More recently the open-set speech perception skills of 80 children who received their CI before three years of age was reported as 54% for open-set words and 81% for open-set sentences (Leigh et al., 2011). These early implanted children have surpassed initial expectations for performance and are achieving speech perception outcomes
that exceed their adult counterparts with post-lingual hearing loss (Leigh et al., 2011). The studies by Dowell, Dettman, Blamey, et al. (2002), Geers, Brenner, et al. (2003) and Leigh et al. (2011) have lacked in their description of the children’s early auditory skills and the development of these skills over time. The present study will address this using a prospective study design over a six year period. This will enable the investigation of early auditory skills and the subsequent development of open-set perception on a single cohort of children.

2.3 Speech production development of hearing impaired children/children using cochlear implants

Description of speech production skills can be divided into two components; the phonetic level and the phonological level. Mastery of both components is required for the development of intelligible speech. The phonetic level relates to the physical production, or ‘articulation’, of speech sounds and assumes no knowledge of the language being spoken (Bauman-Waengler, 2004). In order to communicate effectively a child must develop the ‘repertoire’ of sounds required for intelligible speech in his/her native language. The phonological level of speech production relates to knowledge of, and ability to produce, patterns of sounds that occur in a specific language (Bauman-Waengler, 2004). Speech production skills have been found to predict speech intelligibility; poor intelligibility can result in significant communication breakdown between conversation partners (Ertmer, 2010; Tye-Murray, Spencer, & Woodworth, 1995).

During the first year of life, infants with normal hearing produce a variety of vocalizations, beginning with reflexive vocalisations e.g. cries and coughs, and progressing through a sequence of stages to complex babbling e.g. cooing and jargon babbling. These later non-reflexive vocalizations contain many phonetic features
found in adult language and transition into meaningful speech from 12 months and older (Oller, 1980).

Children with normal hearing will generally acquire all English phonemes by eight years of age (Sander, 1972). More complex speech production skills continue to consolidate into adolescence e.g. morpho-phonemic rules which govern which phonetic form a morpheme will take (English plural s will be pronounced differently in the word dwarves vs cats and the use of different stress for the word record will change the meaning from a noun to a verb) (Menn & Stoel-Gammon, 1993).

The development of speech production for a child with severe-to-profound hearing loss is hindered by their inability to hear the speech production model provided by normally hearing individuals and/or the child’s limited auditory capacity to monitor their own speech. The speech intelligibility of children with profound hearing impairment using conventional amplification has been studied extensively in the past. These children typically had poor speech production skills; with many rated as being unintelligible, or having very low intelligibility, by adult listeners unfamiliar with the speech of children with hearing loss (Gold, 1980; Spencer et al., 2010). Historical reports of speech intelligibility for children with severe-to-profound hearing loss using conventional amplification, suggest that their speech is less than 20% intelligible on average (Osberger, Maso, & Sam, 1993; Smith, 1975). This low level of intelligibility will likely result in significant communication difficulties in all communication settings.

CIs have the capacity to provide children with access to all the sounds of speech, so that they can learn from speakers with normal hearing, and monitor their own speech production. Research has suggested that the improvement in speech perception of children using CIs positively influenced their ability to organise and monitor their own speech production and develop a more sophisticated and adult-like phonological
system (Tye-Murray et al., 1995; Waltzman & Cohen, 1998). A number of studies have documented the wide range of speech production abilities of children using CIs (Connor et al., 2006; Spencer & Oleson, 2008; Tobey, Geers, Brenner, Altuna, & Gabbert, 2003). The majority of children using CIs were rated as having better speech intelligibility compared to peers with similar degrees of hearing loss using HAs (Connor et al., 2006; Flipsen & Parker, 2008; Tobey & Hasenstab, 1991; Tye-Murray et al., 1995). Speech production outcomes have improved over time as a result of longer periods of implant experience, improved hardware and speech processing technology and younger age at implantation; although many children still do not have the equivalent speech production skills/intelligibility of their peers with normal hearing (Chin, Tsai, & Gao, 2003; Leigh, Dettman, Dowell, & Briggs, 2013; Peng, Spencer, & Tomblin, 2004).

It was initially unknown whether children with CIs would follow the same pattern of sound acquisition as their peers with normal hearing, or what their rate of progress would be. Studies of consonant and vowel acquisition in children with CIs suggest that, on average, these children demonstrate a pattern of vocal development and phoneme (or speech sound) acquisition similar to that of children with normal hearing (Ertmer, Young, & Nathani, 2007; Serry & Blamey, 1999), although their rate of development has been reported as slower (Blamey, Barry, & Jacq, 2001).

Serry and Blamey (1999) and Blamey, Barry, and Jacq (2001) evaluated the phonetic development of the same subject group of nine children using CIs for four and six years respectively. Both studies reported that the children using CIs acquired consonants in approximately the same order as children with normal hearing, but made slower progress. Speech development was reported as reaching a plateau after around six years of implant experience and not all sounds had been acquired. The authors suggested that this was likely the result of decreasing neural plasticity, as the
group’s average age at the conclusion of the study (six years post-implantation) was 9.75 years (Blamey, Barry, & Jacq, 2001).

Serry and Blamey (1999) also described the phonological development of their group of nine implanted children. For vowels, monophthongs were mastered earlier and with more accuracy compared to diphthongs. For consonants, nasals, glides and stops were earlier to emerge, while fricatives and affricates were much slower. Improved accuracy of speech sounds with more visible features (e.g. bilabial consonants) was observed compared to velar sounds (produced further back in the vocal tract). These findings were further supported by Blamey, Barry, and Jacq (2001) who also reported that monophthongs were consistently produced more accurately than diphthongs, followed by consonants, while consonant clusters were the least accurately produced. The consistency between these two studies is not surprising given that the studies were completed on the same group of nine children using CIs.

Tomblin, Peng, Spencer, and Lu (2008) investigated the improvement in phonetic accuracy of 27 children using CIs for up to 10 years post implantation. The findings of Tomblin et al. (2008) were consistent with those of Blamey, Barry, Bow, et al. (2001). Tomblin et al. (2008) reported no plateau after six years of implant experience, but did observe a significant decline in the rate of development from six to 10 years post-implantation. Tomblin et al. (2008) also noted that the age when a plateau was observed corresponded to a ‘hearing age’ of approximately eight years for the children using CIs and highlighted that children with normal hearing have typically mastered all speech sounds by eight years of age.

Collectively the above mentioned studies suggest that the speech acquisition process for children using CIs is still developing at the age at which children with normal hearing have mastered speech production, with limited evidence that a plateau in
development has been reached for children implanted between two and five years of age. In all of these studies, the children received their CI after two years of age and in some cases, up to seven years of age. It is possible that speech production development may differ for children who receive CIs at a comparatively younger age e.g. before two years of age and this will be a focus of the present study.

There is little consensus amongst the few studies to report on the speech production skills of children implanted before 12 months of age. A study by Holt and Svirsky (2008) reported that children implanted before age 12 months and those implanted between 12-24 months showed no difference in their speech production development, while two more recent studies found that speech production skills for children implanted before the age of 12 months was significantly better than children who received their CI after 12 months of age (Dettman et al., 2016; Leigh et al., 2013) and equivalent to that of normally hearing children (Leigh et al., 2013). Future research may clarify the critical period during which children should receive CIs in order to facilitate speech production outcomes that are similar to those of children with normal hearing.

According to the theory of Natural Phonology developed by Stampe (1979) a phonological process is a “mental operation that applies in speech to substitute for a class of sounds or sound sequences that present a common difficulty to the speech capacity of the individual, an alternative class identical but lacking in the difficult property” (p.1). Children with normal hearing are limited physiologically in their ability to produce certain speech sounds and as a result use phonological substitutions and simplifications, omitting sound features that are still difficult to produce (Eriks-Brophy, Gibson, & Tucker, 2013). More recently, Bauman-Waengler (2012) defined phonological processes as predictable simplifications, or patterns of errors, used commonly while typically developing children are learning to speak. Given that phonological processes are part of the normal developmental pathway in the gradual
adjustment of a child’s speech to the adult form, as with the acquisition of phonemes, previous research provides definition around the age in which a specific process could still be present, as well as the approximate age by which it should be suppressed by typical development (Eriks-Brophy et al., 2013; Grunwell, 1982, 1987; Stampe, 1979). Children who exhibit atypical phonological process use, display chronological mismatches in process use, or who do not proceed through the expected developmental sequence of process use with suppression are described as having a phonological disorder (Bauman-Waengler, 2012; Hodson, 2007).

Research describing the use of phonological processes by children using conventional amplification and/or CIs generally distinguishes between developmental and non-developmental phonological processes. Developmental processes, as described above, are commonly observed in typically developing children’s speech, and are thought to be simplifications of adult forms that occur due to limitations of children’s motor and/or perceptual abilities (Buhler, DeThomasis, Chute, & DeCora, 2007). Non-developmental processes are infrequently observed in typically developing children’s speech and generally result in reduced intelligibility, as most listeners are unfamiliar with decoding these deviant speech patterns (Buhler et al., 2007).

Children using conventional amplification have been reported to exhibit both developmental processes and non-developmental processes (Meline, 1997; Stoel-Gammon, 1983). In a study of 133 children using HAs, Ching et al. (2010) reported that the most commonly used phonological processes, observed in more than 70% of the group of children, were stopping, gliding and cluster reduction, which are all developmental processes.

Few studies have been published specifically investigating the use of phonological processes amongst children using CIs, with interpretation and generalization limited
by the inclusion of participant groups of less than 10 children (Buhler et al., 2007; Chin & Pisoni, 2000; Flipsen & Parker, 2008; Grogan, Barker, Dettman, & Blamey, 1995). The literature available suggests, that like their counterparts using conventional amplification, children using CIs demonstrated use of both developmental and non-developmental processes, with developmental processes more commonly observed (Chin & Pisoni, 2000; Flipsen & Parker, 2008; Grogan et al., 1995). The most commonly reported developmental processes observed for children using CIs (e.g. stopping, gliding of liquids, cluster reduction and final consonant deletion) are also commonly observed in children with normal hearing (Roberts, Burchinal, & Footo, 1990). Flipsen and Parker (2008) described the pattern of phonological process use for children using CIs as being comparable to that of children with normal hearing. All published research to date that describes the use of phonological processes for children using CIs has been conducted on children who received their CI well beyond the sensitive period for speech development (e.g. beyond 2-3 years of age), it is therefore, not surprising that these children have been reported to use a proportion of non-developmental processes. It is possible that children who receive a CI within the first few years of life may demonstrate reduced prevalence of non-developmental processes and suppress their developmental processes in a timeframe more consistent with their peers with normal hearing. The present study will prospectively investigate the phonological development of children who received their CI at an early age and provide a unique insight into the speech production skills of this group.

### 2.4 Acquisition of language of children with hearing impairment/children using cochlear implants

Acquisition of oral language for a child with normal hearing follows a predictable developmental trajectory; for each chronological year the child would develop the equivalent year in language skills, giving the child a language growth rate of 1.0. For
children with normal hearing, oral language skills are known to develop into late childhood and for some aspects of language, e.g. semantics, development continues through adulthood (Berko Gleason, 2009).

As is the case for the development of speech perception and speech production, presence of a hearing loss may disrupt a child’s ability to develop oral language at a rate comparable to their peers with normal hearing. The effect of a hearing loss on a child’s development of oral language will depend somewhat on the degree of hearing loss (Wake, Poulakis, Hughes, Carey-Sargeant, & Rickards, 2005). The rate of language development for children using HAs (with profound hearing loss) has been reported as ranging from 0.33 to 0.43, suggesting that as these children mature they will become further and further behind their peers with normal hearing (Blamey, Sarant, et al., 2001; El Hakim et al., 2001; Svirsky, Robbins, Kirk, Pisoni, & Miyamoto, 2000).

The acquisition of language is typically measured using standardized assessments of vocabulary and grammatical knowledge. Such standardized measures provide useful information regarding how an individual child is performing compared to a norm reference sample. If administered on multiple occasions, these measures also provide valuable information regarding a child’s language progress over time and can be used to investigate the impact of intervention e.g. cochlear implantation, on a child’s language.

Early reports on language development of children using CIs were limited to case studies. Research conducted in the 1990s was focused on comparing whether children with CIs developed language more quickly than their peers with HAs, or compared development to predictions based on pre-operative language development with HAs. Geers and Moog (1994) compared language progress, over three years, in three
groups of children with CIs, HAs and tactile aids (body-worn aids that provide vibratory or electrical stimulation). On average, the language growth of children with CIs was found to be equal to or exceeded that for the other groups of children, and even approached that of children with HAs who had 20 dB better hearing. A number of subsequent studies, completed in the early 2000s, also demonstrated a marginal advantage on oral language development for children using CIs compared to their profoundly deaf peers using HAs (Blamey, Sarant, et al., 2001; El Hakim et al., 2001; Svirsky et al., 2000). The rate of language development for the implanted children ranged from 0.38 to 0.71 whereas children using HAs (with profound hearing loss) ranged from 0.33 to 0.43. Blamey, Sarant, et al. (2001) further reported that children with CIs were developing language at a rate similar to that of children with a severe hearing loss. Despite these findings, the fact that these children were already delayed in their language development by the amount of time it had taken for diagnosis and implantation to occur, the rate of growth (0.38 to 0.71) resulted in many of the children being delayed by at least one year, and approximately half had a severe language delay (defined as greater than two standard deviations below the mean for children with normal hearing) by the time they entered primary/elementary school. This rate of progress has severe implications for academic achievement and functional literacy outcomes (Sarant, 2012).

Over the past decade, as the average age at implantation has decreased and CI speech processing technology and hardware has become more sophisticated, children using CIs are demonstrating improved language development e.g. Spencer et al. (2010) reported that some children using CIs acquired oral language similar to children with mild-to-moderate hearing loss. Given these promising results, the focus has changed to comparing the progress of children with CIs to that of their peers with normal hearing. Several studies have now demonstrated that children who have received their cochlear implant(s) at very young ages can achieve spoken language
development at similar rates to children with normal hearing (Connor et al., 2006; Dettman et al., 2007; Duchesne, Sutton, & Bergeron, 2009; Leigh et al., 2013; Svirsky et al., 2004; Tomblin, Barker, Spencer, Zhang, & Gantz, 2005). It has also been reported that some children with CIs are able to learn language more quickly than the average child with normal hearing and therefore ‘catch up’ some of the language delay that occurred before they received a cochlear implant, with reports of language development at age-appropriate levels around the time the children entered primary/elementary school (Leigh et al., 2013; Yoshinaga-Itano, Baca, & Sedey, 2010).

As with speech perception and speech production, there is still a large amount of variation in language skills observed between individuals and between different populations of children using CIs (Spencer, 2004), with significant language delays commonly reported (Ching et al., 2010; Connor et al., 2000; Nikolopoulos, Dyar, Archbold, & O'Donoghue, 2004; Sarant, Holt, Dowell, Rickards, & Blamey, 2009; Young & Killen, 2002). Further research is warranted to explore in detail the factors that influence oral speech and language outcomes for children who use cochlear implants. A key focus of the present study will be to identify the factors that are associated with the oral speech and language outcomes for a cohort of children who receive their CI at an early age.

2.5 Early diagnosis of hearing loss

Past research has suggested that early diagnosis of hearing impairment and subsequent early access to appropriate intervention options (HAs and CIs) and services, improves speech and language outcomes and minimises developmental delays (Apuzzo & Yoshinaga-Itano, 1995; Kennedy et al., 2006; Markides, 1986; Robinshaw, 1995; White & White, 1987; Yoshinaga-Itano, 2003; Yoshinaga-Itano, Sedey, Coulter, & Mehl, 1998). When early identification is paired with early
intervention, improvements in speech and language development for some children has been found to be comparable to that of hearing children of similar age and development (Dettman et al., 2007; Leigh et al., 2013; Yoshinaga-Itano et al., 1998).

In the late 1980s, White and White (1987) described “intervention age is a compound concept” (p.10) encompassing several related events known to impact on communication outcome. These include: age of diagnosis (Rubin, 1978), age of onset of training of residual hearing (Graham, 1976), age of HA fitting (Bench, 1978), age of involvement of the family (Greenstein, Greenstein, McConville, & Stellini, 1975), age of enrolment into an early intervention program (Kretschmer & Kretschmer, 1978) and others. White and White (1987) studied a group of 46 infants with severe-to-profound hearing impairment with a pre-lingual onset and no additional disabilities. They reported significantly better language scores for those children whose hearing loss was identified before 18 months (average age of identification 11.9 months) of age compared to those identified after 18 months (average age of identification 19.5 months). There was, however, very little difference between the age of HA fitting for the two groups. The average age of aiding for the early identified group was 28 months compared to 30 months for the later identified group. This finding would support the belief that early diagnosis is the primary predictor of outcome rather than early access to sound. It is possible, however, that the age of HA fitting had no direct impact on outcome due to the degree of hearing loss of the children included in this study; many of the children in the study would not have had sufficient access to the sounds of speech to facilitate development of oral language, even with the use of appropriate HAs.

The importance of early diagnosis of hearing loss was highlighted further by Yoshinaga-Itano et al. (1998) in a highly cited study which demonstrated the importance of identification of hearing loss before six months of age for
communication outcomes. Their study included children with a wide range of degrees of hearing loss and found that the language advantage was irrespective of test age, communication mode, degree of hearing loss and socioeconomic background. Age of HA fitting and enrolment into an early intervention program was closely linked to age of identification of hearing loss. Almost all children (96%) in this study were enrolled in the same intervention program (Colorado Home Intervention Program). The program was family focussed and provided in the child’s home by an audiologist, speech-language pathologist or deaf educator who visited the family for approximately one hour per week. Although conducting a study in this manner controlled for the variation in quality and frequency of service provision it limited the ability to generalise these findings to the wider population of children with hearing impairment, some of whom may receive little to no early intervention support.

2.6 Early cochlear implantation

The age at which a child receives a CI is well accepted as having a significant impact on the speech perception, speech production and language outcomes for children with severe-to-profound hearing loss (Connor et al., 2006; Dowell, Blamey, & Clark, 1995; Hammes et al., 2002; Holt & Svirsky, 2008; Kileny et al., 2001; Kirk et al., 2002; Lesinski-Schiedat et al., 2004; Manrique et al., 2004; Nikolopoulos et al., 1999; Schauwers et al., 2004; Svirsky et al., 2004; Tomblin et al., 2005; Waltzman & Cohen, 1998; Waltzman & Roland, 2005; Zwolan et al., 2004). Despite the support for children receiving CIs at a young age in the above listed studies, the majority of children in these studies already demonstrated a significant speech and/or oral language delay at the time of implantation give that the majority of children received their CI after two years of age.

One of the earliest published studies providing support for the provision of CIs to children younger than two years of age was completed by Waltzman and Cohen
The authors documented the speech perception benefits for 11 children who received the Nucleus 22-channel CI between the ages of 14 and 23 months. The children were followed up for a period of five years post-implantation. At the time of publication, however, only two had completed the five-year post-implantation evaluation. Of the nine children who had completed their one year post-implantation assessment, all achieved speech perception skills at a rate equal to or faster than children who had received the implant between two and five years of age. The data also suggested that the children who received a CI at a younger age could achieve and even surpass the level of speech perception performance obtained by the later implanted children. Waltzman and Cohen (1998) concluded that their finding had implications for the optimal development of oral speech and language skills. That is, if access to sufficient speech understanding is possible at a younger age, more typical patterns of speech production and language are likely to develop.

Hammes et al. (2002) described the speech perception and oral language outcomes of 10 children who received a CI at or before 18 months of age, with six months or more experience using their device, and compared these children to those who had received their implants at an older age. Children with cognitive delay, progressive hearing loss or those who had stopped using their device were removed from the study. Language and speech perception measures were administered. For the speech perception measure (PBK words), only three children under 18 months were able to complete the task. Children who lacked the auditory ability to complete the task were not included. Although the children who received CIs before 18 months achieved higher mean speech perception scores when compared to the older groups, it is difficult to draw conclusions based on such small numbers (three in the CI before 18 month group, 11 in 19 to 30 month group, eight in 31 to 40 month group and eight in 41 to 48 month group). In order to generalise these findings to the wider population of children using CIs it would also be relevant to include those children who had
reached the chronological age appropriate to complete the task but lacked the auditory abilities i.e. by assuming zero. The authors concluded that children who received a CI before 18 months of age demonstrated smaller language delays compared to children who received implants after 18 months. There were, however, only four children out of the 10 implanted before 18 months that had spoken language skills within six months of their chronological age. It could therefore be concluded that 18 months is not early enough for children to receive a CI if the goal is for them to achieve age appropriate speech and language.

Connor et al. (2006) further explored the benefits of early implantation by reporting on speech production and vocabulary for a group of 100 children using cochlear implants. The study cohort included 21 children who received their CI between 1-2.5 years of age and 15 children implanted between 2.6-3.5 years of age. The early implanted group demonstrated significantly greater rates of vocabulary growth for the first three years after implantation compared to children who received their implant after 2.5 years. By four years post-implant, the language growth for children in both groups was similar. Children implanted before 2.5 years generally demonstrated receptive vocabulary growth-curves that approximated those observed for children with normal hearing sensitivity. The authors used the growth rates to predict the vocabulary score for children in each group at six years of age. It was predicted that children implanted before 2.5 years would fall within low-normal limits (standard score of 90) for a child with normal hearing at six years of age. Children implanted between 2.6 and 3.5 years were predicted to be more than one standard deviation below the mean (standard score of 79). These findings suggested that language growth for children implanted before 3.5 years can approximate that of normally hearing peers. This study provided some of the first evidence that early implanted children had the potential to develop age appropriate language skills. Follow up for this study was limited to three year post-implantation. The varying age at
implantation for the participants led to an equally wide range of chronological ages for the children at the final data point. The resulting conclusion that children implanted between 2.6 and 3.5 years would have a language delay at six years of age whereas children implanted before 2.5 years would fall in the normal range was a prediction only and not based on actual data.

Although there are significant advantages for implanting children at an early age, these children rarely demonstrate age appropriate oral language skills. If children were to receive a CI within the first year of life this language delay may be significantly reduced. An increasing number of studies have now described the speech perception (Colletti et al., 2005; Holt & Svirsky, 2008; Lesinski-Schiedat et al., 2004; Schauwers et al., 2004; Waltzman & Roland, 2005), speech production (Colletti et al., 2005; Leigh et al., 2013) and oral language benefits (Dettman et al., 2007; Holt & Svirsky, 2008; Leigh et al., 2013) of children receiving CIs before 12 months of age.

Colletti et al. (2005) compared the onset of babbling (a precursor to speech production and oral language) and auditory skills of 10 children who received CIs before 12 months of age with a control group of 10 normally hearing children and with a group of children who received implants over 12 months of age. Due to the relatively young age of the children in this study, description of auditory performance was limited to the CAP, an indirect measure of auditory performance. Follow up was also limited to two years post-implant. The group of early implanted children’s babbling and auditory abilities developed at a rate similar to the their normal hearing peers and at an earlier chronological age to those children receiving implants over 12 months of age.

Lesinski-Schiedat et al. (2004) investigated the outcomes of 27 children who received a CI before 12 months of age and 89 children implanted between the ages of one and
two years. For the first 12 months post-implantation, outcomes were evaluated using the German version of the Meaningful Auditory Integration Scale (MAIS). Formal speech perception measures were used to describe the children’s outcome once they were old enough to complete the task. At the time of publishing seven children in the younger group and 42 children in the older group had reached two years post-implantation. Based on the speech perception scores of the two groups the authors concluded that the younger group demonstrated better results in terms of development of hearing and speech understanding and that the outcomes for this group were more similar to the child’s chronological age than length of time post-implant. The conclusions of this study were limited to a description of speech perception outcome and although an appropriate measure of hearing potential, it fails to describe a child’s overall oral communicative competence. This study also included 22 children where the cause of the hearing loss was meningitis. The proportion of children with aetiology of meningitis was higher (30%) in the younger group than in the older group (16%). These children would have had prior auditory experience and this may have confounded the results in this study.

Speech production, measured as the onset of babbling and babbling spurt, has been described as following a similar pattern of development to children with normal hearing if the child with hearing impairment received CIs in the first year of life (Colletti et al., 2005; Schauwers et al., 2004). In the studies by Schauwers et al. (2004) and Colletti et al. (2005), post-implantation follow up was limited to one and two years respectively. It is therefore unclear whether these encouraging findings for babbling onset and spurt develop into age appropriate speech production skills when the children reach school age.

One of the first published studies to describe the oral language outcomes of children implanted before 12 months of age was completed by Dettman et al. (2007). The
study compared the rate of language growth of 11 children implanted between 6-12 months with 36 children implanted between 1-2 years of age and found that the earlier implanted group demonstrated a smaller language delay and were developing language at a rate similar to their normally hearing peers. The description of outcome was limited to 2-2.5 years post-implantation and only included language as the measure of outcome. It is not clear if the advantages for early implant found by Dettman et al. (2007) would be maintained at older ages. It is possible that the later implanted children could catch up. To address this possibility, it is important to investigate outcomes beyond the third year of life and to control for developmental differences of children tested at varying ages by evaluating all participants at the same chronological age (e.g. at five years of age).

Holt and Svirsky (2008) described the speech perception and language outcomes for early implanted children. The authors observed children’s spoken language development for up to two years post-implantation. Spoken language scores and rate of development were investigated along with four covariates (unaided pure-tone average, communication mode, gender and estimated family income) as a function of age at implantation. In general, the developmental trajectories of children implanted earlier were significantly better than those of children implanted later. However, the children implanted before 12 months of age failed to show significant performance differences on two of the three outcome measures compared to those children implanted between one and two years of age. The advantage of implanting children before 12 months of age was only evident in receptive language development, not expressive language or word recognition development. Age at implantation did not significantly influence the rate of word recognition development, but did influence the rate of both receptive and expressive language acquisition; children implanted earlier in life had faster rates of spoken language acquisition than children implanted later in life. Results suggest a clear advantage for implanting before the age of two, with only
weak evidence for implanting before 12 months of age. Conclusions drawn from both the Dettman et al. (2007) and Holt and Svirsky (2008) studies are limited by the relatively small number of children implanted before 12 months of age, 11 and six children respectively. In both studies, follow up of the children was limited to two and half years post-implantation. It is possible that the benefit of implanting before 12 months may be more evident with longer term follow up and larger participant numbers. The present study will address this limitation by assessing the participants prospectively over a six year period with the final evaluation occurring when the children are approximately five years of age.

Leigh et al. (2013) extended on the original cohort of children in the Dettman et al. (2007) study by increasing the number of participants, expanding the test battery and increasing the duration of follow-up. Leigh et al. (2013) found no significant difference in the language growth for children who received a CI between 6-12 months compared to those implanted between 13-24 months. A difference did exist when the children’s language was assessed three years post-implantation; children implanted between 6-12 months, on average, demonstrated vocabulary skills within the normal range for hearing peers, the group implanted between 13-24 months were exhibiting a language delay. The findings of Holt and Svirsky (2008) and Leigh et al. (2013) appear to be in contrast to the findings of Dettman et al. (2007) who found a significant difference in growth rate for children implanted before 12 months and those implanted between one and two years of age. These apparently different outcomes can be resolved by applying the language growth model discussed in the Leigh et al. (2013) paper to the data from the Dettman et al. (2007) study. The younger group in this earlier study demonstrated language growth equivalent to their normally hearing peers whereas the older children’s rate of receptive language growth was significantly poorer, but allowing for the larger language delays when implanted
later would make the data from Dettman et al. (2007) consistent with the findings of Leigh et al. (2013).

Leigh et al. (2013) also investigated the speech production and speech perception of the two groups of children. Speech production was described as following a similar pattern to that of normal hearing children, although was found to be delayed for both groups. No significant difference in speech perception skills was observed between the two groups. This compilation of findings suggested varying sensitive periods for the three aspects of communication investigated in the study. Leigh et al. (2013) concluded that the critical period for language development was within the first year of life, whereas the critical period for speech perception extended beyond the first year of life. The findings also suggested that the critical period for speech production was earlier than for language and speech perception.

The work of Houston and Miyamoto (2010) and Houston, Stewart, Moberly, Hollich, and Miyamoto (2012) has also provided some insight into the specific benefits of implantation during the first year of life. Houston and Miyamoto (2010) reported differences in the word learning and vocabulary skills of children (with minimal pre-CI hearing) who received their CI in the first year of life compared to the second year of life but reported no difference in speech perception performance. Based on this preliminary finding, Houston and Miyamoto (2010) suggested that there is an earlier sensitive period for word learning than for central auditory processing skills (as measured by speech perception). The possibility of these differing sensitive periods will be explored in the present study by the evaluation of receptive vocabulary skills, an outcome measure directly related to word learning, and speech perception skills.
2.7 Factors affecting communication outcomes for children using a cochlear implant

The extent to which a child will use the auditory information provided by a CI to develop oral speech and language skills is affected by both independent child related factors and environmental factors. Numerous studies have attempted to identify the factors that affect the speech perception, speech production and language outcomes for children using cochlear implants. The following independent child characteristics have been frequently reported as impacting on performance: age at onset of hearing loss (Fryauf-Bertschy et al., 1992; Osberger et al., 1991; Sarant et al., 2001; Staller, Dowell, et al., 1991), degree of pre-implant residual hearing (Cowan et al., 1997; Dettman, D’Costa, et al., 2004; Eisenberg et al., 2000; Sehgal et al., 1998; Zwolan et al., 1997), presence of a developmental delay (Dettman, Fiket, et al., 2004; Dowell, Dettman, et al., 2002; Isaacson et al., 1996; Palmieri, Forli, & Berrettini, 2014; Pyman et al., 2000; Waltzman et al., 2000) and gender (Geers, Nicholas, et al., 2003). The child’s outcomes (measured as speech perception, speech perception and/or language performance) with a CI cannot be predicted by these factors alone.

The following environmental, and somewhat controllable, factors have also been identified as affecting outcome; age at identification of hearing loss (Apuzzo & Yoshinaga-Itano, 1995; Markides, 1986; Robinshaw, 1995; White & White, 1987; Yoshinaga-Itano, 2003), age at cochlear implantation (Connor et al., 2006; Dowell et al., 1995; Hammes et al., 2002; Kileny et al., 2001; Kirk et al., 2002; Lesinski-Schiedat et al., 2004; Manrique et al., 2004; Nikolopoulos et al., 1999; Schauwers et al., 2004; Svirsky et al., 2004; Waltzman & Cohen, 1998; Waltzman & Roland, 2005; Zwolan et al., 2004), CI and speech processor technology (Cowan et al., 1995; Moog & Geers, 2003; Osberger et al., 1996), number of active electrodes (Blamey et al., 1992; Geier & Norton, 1992; Moog & Geers, 2003; Staller, Dowell, et al., 1991), educational placement/mode of communication (Connor et al., 2000; Geers, Brenner, et al., 2003; Geers et al., 2002; Kirk et al., 2002; Tobey et al., 2003; Wie et al.,
2007), family characteristics and participation in the intervention program (Bertram & Pad, 1995; Calderon & Low, 1998; Easterbrooks et al., 2000; Geers & Brenner, 2003; Moeller, 2000; Musselman et al., 1989; Yanbay, Hickson, Scarinci, Constantinescu, & Dettman, 2014).

Impact of age at diagnosis of hearing loss and age at CI has been described in detail in previous sections (refer to sections 2.5 and 2.6). The subsequent sections will briefly describe the current state of knowledge for the additional independent and environmental factors known to impact on communication outcomes for children using CIs.

2.7.1 Age at onset of hearing loss

A number of studies have documented that children with later onset of deafness and shorter period of auditory deprivation prior to receiving a CI demonstrate better speech perception skills compared to children with earlier onset of hearing loss (Fryauf-Bertschy et al., 1992; Osberger et al., 1991; Sarant et al., 2001; Staller, Dowell, et al., 1991). This difference, however, is not evident when only those children with pre-lingual onset (before three years of age) of hearing loss are considered (Miyamoto, Osberger, Robbins, Myres, & Kessler, 1993).

2.7.2 Pre-implant residual hearing

In a population study of hearing impaired children’s language outcomes at 7-8 years of age, Wake et al. (2005) reported that language scores for 86 children were poorer with increasing severity of hearing loss, even when adjusted for age at hearing loss diagnosis and IQ. Useful pre-implant residual hearing and better pre-implant pure-tone average have been found to have a positive association with post-operative speech perception and language outcomes in several studies (Cowan et al., 1997;
Dettman, D'Costa, et al., 2004; Eisenberg et al., 2000; Niparko et al., 2010; Sehgal et al., 1998; Zwolan et al., 1997). Collectively these studies support the concept that increased auditory experience prior to implantation may facilitate the development of communication skills post-implantation. In contrast, a study by Tyler, Fryauf-Bertsch, Kelsay, et al. (1997) found no association between pre-implant residual hearing and speech perception outcome for children using cochlear implants. Tyler, Fryauf-Bertsch, Kelsay, et al. (1997) reported higher speech perception scores for children with congenital onset of hearing loss compared to those with pre-lingual acquired hearing loss. The authors did not provide an explanation as to why having no exposure to sound lead to better word understanding compared to having limited exposure. The only plausible explanation provided to support this finding was that ‘perhaps the acoustic stimulation has established patterns in the brain that are dramatically different from, or at least inhibit, the latter patterns established by electrical stimulation’ (p. 186). Alternately, this finding may be influenced by the underlying aetiology of hearing loss rather than pre-implant duration to the exposure of sound. The congenital group was primarily made up of children with unknown causes, whereas the acquired pre-lingual group was composed primarily of children with meningitis. Hearing loss is only one of the many known comorbidities associated with meningitis (Isaacson et al., 1996). Neurological complications have been reported to occur in 20-30% of cases following meningitis and more subtle comorbidities such as learning disability, perceptual and attention deficits and behavioural problems are potentially even more prevalent (McIntyre, Jepson, Leeder, & Irwig, 1992; Taylor et al., 1990). Presence of an additional disability has been associated with poorer speech perception performance for children using CIs (Dettman, Fiket, et al., 2004) and this relationship will be discussed in further detail in the subsequent section. Tyler, Fryauf-Bertsch, Kelsay, et al. (1997) did not appear to screen for or exclude children on the basis of an additional disability so it is likely
that the high proportion of children with meningitis in the acquired hearing loss group would have confounded the findings in their study.

### 2.7.3 Developmental delay

The presence and severity of additional disabilities, particularly cognitive delays, has been described as having a negative relationship with speech perception outcomes and rate of progress amongst children using CIs (Dettman, Fiket, et al., 2004; Dowell, Dettman, Blamey, et al., 2002; Holt & Kirk, 2005; Isaacson et al., 1996; Pyman et al., 2000; Waltzman et al., 2000). In a systematic review of 41 published studies describing the outcomes for children using CIs with additional disabilities, Palmieri et al. (2014) concluded that children with additional disabilities, on average, improved in most outcomes measures, although often to a lesser degree, and progress was slower when compared to peers using CIs without an additional disability.

Waltzman et al. (2000) examined 31 children with multiple disabilities 12 months after receiving their cochlear implant. Overall, the children were able to achieve measurable benefit from using their implants, including improved auditory and communication skills, increased social interactions and greater connection with their external environment. They did, however, exhibit significantly slower rates of growth of speech perception skills compared to children using CIs without additional disabilities. Pyman et al. (2000) also demonstrated that children with evidence of cognitive and/or motor delays tended to progress more slowly than other children and often did not achieve open-set speech understanding. The authors classified cognitive and motor delays as either normal or delayed. Cognitive and motor delays often co-occurred therefore the children were grouped according to the presence or absence of motor and/or cognitive delay. Interpretation of the Waltzman et al. (2000) and Pyman et al. (2000) studies was limited to absence or presence of a cognitive/motor
delay given the lack of differentiation between children with different degrees of delay.

Nikolopoulos, Archbold, Wever, and Lloyd (2008) compared the speech intelligibility of 67 children using CIs with an additional disability to a control group of 108 children using CIs without additional disabilities. The children’s speech was rated using the speech intelligibility rating (SIR) scale five years after receiving their cochlear implant. The authors reported that children with additional disabilities were less likely to develop intelligible speech compared to their peers with no additional disabilities, with some not able to develop speech at all. They also found that the total number of additional disorders had the strongest correlation with the outcome. The outcome reported in this study was limited to speech intelligibility, which, although an important component of oral communication, only provides a narrow picture of a child’s overall communicative competence. Degree of additional disability was also not considered, so conclusions are limited in their generalizability to the large proportion of children using CIs with varying degrees of additional disability.

Although several studies have identified a negative association between developmental delay and speech perception outcome (Dowell et al., 2002; Isaacson et al., 1996; Pyman et al., 2000; Waltzman et al., 2000) few have investigated the degree of the developmental delay and its relative impact on speech perception outcome. One of the few studies to differentiate between children using CIs with different degrees of cognitive delay was completed by Dettman, Fiket, et al. (2004). The study examined whether the severity of cognitive delay was associated with poorer speech perception outcomes. The authors concluded that there was a significant association between speech perception category [as used by Dowell et al. (1995)] and degree of cognitive delay. Children with moderate and severe
developmental delay had significantly poorer speech perception than children with borderline, normal or above average cognitive function.

2.7.4 Gender

There is evidence in the normal hearing population of children that females exhibit a verbal advantage over males, especially in early vocabulary development, when assessed at the same chronological age (Fenson et al., 1994; Fenson et al., 2000). This pattern is also evident amongst children with hearing impairment learning oral language (Easterbrooks & O'Rourke, 2001) and children who received a CI before five years of age (Geers, Nicholas, et al., 2003).

In a large study of eight to nine year old children with pre-lingually acquired hearing impairment who received a CI by five years of age, Moog and Geers (2003) reported better speech production, language and reading outcomes for girls compared to boys. Higher performance was obtained for girls than for boys in all outcome areas, except speech perception.

In contrast, Holt and Svirsky (2008) observed children’s spoken language development for up to two years post-implant and found no effect of gender. Spoken language scores and rate of development were evaluated along with covariates (unaided pure-tone average, communication mode, gender and estimated family income) as a function of age at implantation. The authors found no effect of gender on word recognition or rate of development of language.

2.7.5 Speech processor and speech processor strategy

As technology advances, more sophisticated speech processors and speech processing strategies have emerged. For the Nucleus® range of devices, it is well established that the SPEAK processing strategy enhanced the speech perception performance of both
children and adults, compared to earlier superseded strategies, F0/F1/F2 and MPEAK (Cowan et al., 1995; Dowell, Dettman, et al., 2002; Sehgal et al., 1998; Skinner et al., 1994; Tobey et al., 2003).

Dowell, Dettman, Blamey, et al. (2002) analysed the speech perception performance of 102 children using either the MPEAK or SPEAK speech processing strategies. A total of 318 test scores on the PBK word test were obtained; 131 from children using the MPEAK strategy and 187 using the SPEAK strategy. Results provided evidence to support the improvements typically seen in speech perception performance when using SPEAK compared to MPEAK. Step-wise multiple regression analysis revealed that speech processor strategy explained 16% of the variance in the children’s speech perception scores.

Benefits for the current commercially available sound coding strategies for the Nucleus® devices (SPEAK, ACE and CIS) over one another is not well established, with some studies indicating a difference in performance between strategies (Pasanisi et al., 2002; Psarros et al., 2002) while others indicate equivalent performance (Skinner et al., 2002).

Few studies have explored whether children obtain additional improvements in speech perception scores when using the ACE speech processing strategy compared to SPEAK. Psarros et al. (2002) used a time series experimental design (ABA) to assess speech perception results of seven children using the SPEAK speech processing strategy compared to the ACE speech processing strategy. All children had at least six months experience with the SPEAK strategy before initial testing (condition A of the ABA design) commenced. The children were then programmed with and had 10 weeks take home experience using the ACE strategy prior to speech perception testing (condition B). The children were then re-programmed with the SPEAK strategy, which
they used for four weeks before completing the final phase of speech perception testing (condition A). The researchers found that speech perception scores were significantly higher when the children were using ACE compared to SPEAK. However, analysis of individual scores suggested that the benefit from the ACE strategy was highly variable. A similar study conducted by Pasanisi et al. (2002) included nine congenitally hearing impaired children. The researchers reported significantly higher speech perception scores, in quiet and background noise, for the children when using ACE compared to SPEAK. The results of both these studies must be interpreted with caution as they only include very small participant numbers.

2.7.6 Number of active electrodes

There have been variable reports on the impact of the number of active electrodes available in the literature, with some studies finding an association between an increased number of active electrodes and better speech perception performance (Blamey et al., 1992; Geier & Norton, 1992; Moog & Geers, 2003; Staller, Dowell, et al., 1991) and others concluding there was no relationship (Dowell et al., 1995; Sarant et al., 2001).

As the number of active electrodes increases, the CI is able to provide stimulation to a wider area of the cochlear, hence an increased number of nerve fibres. However, for the recipient to obtain the anticipated benefit from an increased number of electrodes they must be able to discriminate between the electrodes (therefore receive more spectral information).

Studies involving adults have shown that a larger number of active electrodes are associated with better speech perception performance (Blamey et al., 1992; Geier & Norton, 1992). Studies involving children have also found a significant positive association between the number of active electrodes and speech perception and language performance (Moog & Geers, 2003; Staller, Dowell, et al., 1991). Despite these
noteworthy findings the exact number of electrodes required to provide good speech perception and language performance is not defined. The optimal number of electrodes is hard to identify because speech and language performance is also affected by the number of surviving neural elements, which cannot be quantified, and therefore these two factors are often confounded. Dorman, Loizou, Kemp, and Kirk (2000) suggested that if children have at least eight to 12 active electrodes that they will show substantial improvements in their speech perception and language acquisition in quiet conditions.

2.7.7 Educational placement / Mode of communication

The debate regarding choices for the educational placement and mode of communication for children with hearing impairment is complex and has received significant attention in the literature. Education of hearing impaired children has evolved over several decades and as a result the terminology used to define the various modes of communication used by hearing impaired children has also changed. Two main communication approaches have emerged; aural-oral communication (AO) and total communication (TC). The AO approach stresses the importance of verbal interactions so that the child can use their hearing to facilitate speech production and oral language. The TC approach supplements auditory information with visual information, including sign language and lip-reading to teach speech and language skills. Sign language is a language developed by the deaf community and can meet all of person-to-person communication (Moores, 2010). Sign languages may range from a local community to one shared on a multinational basis and frequently do not have the same grammatical structure or boundaries as the spoken languages used in the same geographical region (Moores, 2010). For the purpose of this study, the terms AO and TC, as defined above, will be used when referring to educational placement and/or mode of communication.
Many studies investigating the effects of communication mode on the language development of children with hearing impairment have concluded that there is no clear advantage of one mode of communication over the other (Connor et al., 2000; Dawson, Blamey, Dettman, Barker, & Clark, 1995; Kirk et al., 2002; Robbins, Bollard, & Green, 1999) and that the best approach will depend on the individual child and family circumstances (Musselman, Lindsay, & Wilson, 1988). Other studies suggest that some populations of children with hearing loss will achieve better oral language outcomes in AO environments (Dowell, Dettman, Blamey, et al., 2002; Sarant et al., 2001).

Literature specifically investigating the choice of communication mode for children using CIs suggests a complex relationship between mode of communication and age at implantation for speech perception outcomes (Bertram & Pad, 1995; Hellman et al., 1991), open-set word recognition (Kirk et al., 2002), measures of consonant production, receptive and expressive vocabulary development (Connor et al., 2000) and tests of receptive and expressive language (Kirk et al., 2002).

Dowell, Dettman, Blamey, et al. (2002) investigated the effect of communication mode of 102 children using cochlear implants. The AO group included 61 children and the TC group included 41 children. Multi-variate analysis was conducted on a number of factors. Results suggested that children who used a purely AO approach performed significantly better than those children using a TC approach on speech perception testing. Similar findings have been reported in several other studies (Dowell et al., 1995; Meyer, Svirsky, Kirk, & Miyamoto, 1998; Osberger, Zimmerman-Phillips, & Koch, 2002; Sarant et al., 2001). In contrast, Robbins et al. (1999) investigated the language skills of 23 children who received their CI between two and five years of age and found no difference between the children using the AO communication approach compared with children using the TC approach. This finding has been subsequently
been replicated. Connor and Zwolan (2004) investigated several factors likely to influence the reading skills of 91 children using cochlear implants. They found no effect of pre-implant communication mode on the children’s reading skills when other variables (e.g. vocabulary score and early implantation) were controlled. Similarly, Yanbay et al. (2014) reported no significant differences in language outcomes for 42 children using cochlear implants, separated into three groups based on the communication approach used by the family (auditory-oral, auditory-verbal therapy and sign-spoken language) after adjusting for potential covariates.

Although there is some evidence to suggest that children using AO outperform children using TC on speech perception tasks, this does not necessarily imply a causal relationship. Many of the studies mentioned above have been criticised as they may reflect selective placement issues. For example, children with better spoken language and better unaided hearing thresholds may be more likely to be placed within AO settings. Further controlled investigation of this factor is clearly warranted.

2.7.8 Family characteristics and participation in intervention program

The impact of family characteristics for children using CIs has not been well documented in the literature. Of the studies that have addressed family characteristics, the following factors have been reported as influencing outcomes for children with hearing impairment: hearing status of the parents (Geers & Brenner, 2003), ethnicity (Geers & Brenner, 2003), family dynamic/intactness (Calderon & Low, 1998; Geers & Brenner, 2003), socio-economic status (Easterbrooks et al., 2000; Geers & Brenner, 2003; Holt & Svirsky, 2008), maternal education (Ching & Dillon, 2013) and parent participation in the intervention program (Bertram & Pad, 1995; Geers & Brenner, 2003; Moeller, 2000; Yanbay et al., 2014).
When reviewing the impact of age at enrolment in early intervention on language outcomes of children with hearing impairment at five years of age, Moeller (2000) proposed a rating system to characterize parent involvement in the early intervention program. Family involvement was rated retrospectively by interventionists who had extensive contact with families in the study. The interventionists were given specific descriptions of characteristics representing each category and were asked to consider issues such as adjustment to the child’s hearing loss, session participation, effectiveness of communicating with the child and advocacy efforts. Ratings were assigned into one of the following five categories; 1=limited participation, 2=below average participation, 3=average participation, 4=good participation and 5=ideal participation. One hundred and twelve children were assessed for vocabulary skills and verbal reasoning. Consistent with the findings of Yoshinaga-Itano et al. (1998) and others authors, there was a significant negative correlation between age at enrolment at early intervention and vocabulary skills. There was however, also a significant correlation between family involvement and vocabulary skills (r=0.65, p<0.01 compared to r=-0.46, p<0.01). Regression analysis was used to further explore the relationships. Age at enrolment and family involvement accounted for 11.4% and 35.5% of the variance in the children’s vocabulary respectively. These findings highlighted the importance of both factors and to the important contributions families make to outcomes for their children. Parental involvement in a child’s therapy and educational program has also been cited as being essential to the child’s linguistic development for children using CIs (Bertram & Pad, 1995).

Socioeconomic status (SES) has been reported to influence developmental outcomes in the typically developing population of children (Bornstein, Haynes, & Painter, 1998; Hoff-Ginsberg, 1991; Hoff, 2003) and those with hearing loss (Connor & Zwolan, 2004; Easterbrooks et al., 2000; Holt & Svirsky, 2008; Niparko et al., 2010). Easterbrooks et al. (2000) conducted a retrospective review of 72 children with
hearing impairment, attending auditory verbal therapy (AVT), to determine the child and family characteristics that were associated with positive outcomes. It was reported that children most likely to succeed in AVT were from affluent families and were more likely to be females. Significantly reduced language learning rates for children using CIs have been associated with lower SES (Holt & Svirsky, 2008; Niparko et al., 2010). In a highly cited study involving 181 children using cochlear implants, Moog and Geers (2003) reported that higher SES was associated with better post-operative outcome in the domains of speech production, spoken language, total language and reading. They found no association between SES and speech perception outcomes. Connor and Zwolan (2004) also found an association between higher SES and better reading skills amongst a group of 91 children using cochlear implants. In contrast to the above mentioned two studies, Yoshinaga-Itano et al. (1998) reported that SES did not appear to be associated with language development in a sample of 150 children with hearing impairment. Follow up in the Yoshinaga-Itano et al. (1998) study was limited to the first three years of life. It is possible that the influence of SES becomes more relevant as the child matures. This issue will be addressed in the present study using a prospective study design, with each participant evaluated over a minimum six year period.

From a survey of 247 children using cochlear implants, Hyde, Punch, and Grimbeek (2011) found that better outcomes were associated with city dwellers only and suggested that this was possibly because such families could avail themselves of more resources for their children with cochlear implants. These findings are consistent with prior studies of children with normal hearing that suggest that children from lower SES homes are exposed to a narrower range of language due to reduced parental attention and talking (Walker, Greenwood, Hart, & Carta, 1994). Children in lower SES households received less encouragement to talk and ultimately
experienced deficits in language and academic performance when they entered school.

Hoff (2003) suggested that the relationship between rate of language development of children with normal hearing and SES was primarily mediated by factors related to maternal speech. Bornstein et al. (1998) and Hoff-Ginsberg (1991), reported that mothers who lived in suburbs in a higher SES bracket provided their children with normal hearing with more opportunities to pick up new language skills by providing more words and longer utterances during normal day-to-day conversations. This gave children additional opportunities to learn from speech that they heard in their surroundings, allowing imitation of words and utterances and practice through conversation with the parent.

Maternal education has been found to be a significant predictor of language development in children with normal hearing at two and four years of age (Reilly et al., 2010). Earlier research supported this finding for language but reported no association between maternal education and speech production for children with normal hearing (Dollaghan et al., 1999). Lack of effect for maternal education on speech production has been also been described for children with hearing impairment (Eriks-Brophy et al., 2013).

In a large population based study, maternal education was found to be a significant predictor of global language scores for 451 children with hearing loss assessed at three years of age (Ching & Dillon, 2013). Global language scores were higher for children of mothers who had completed university education compared to children of mothers who had completed less than or equal to 12 years of schooling. Quittner et al. (2013) suggested that the effect of maternal education was related to the quality and quantity of communicative input received by children in their home environment.
Parental hearing loss was not found to make any difference in psychosocial difficulties for a group of 334 children with hearing impairment (Dammeyer, 2010). The same may not be true however, for oral language development. To date it has not been possible to document the impact of parental hearing status on performance of children who receive a CI due to the small number of children of hearing impaired parents who present for cochlear implantation (Geers & Brenner, 2003). Similarly the effect of ethnicity and birth order for children using CIs has received little attention in the literature.

2.8 Assessment of hearing loss in infants

When considering the provision of CIs to children as young as six months of age it is important to consider the methods for establishing the degree of hearing loss. The level of hearing in each ear needs to be assessed with accuracy prior to a recommendation regarding cochlear implantation.

Behavioural audiometric testing is considered by most to be the "gold standard" for determining hearing thresholds in children (Norton et al., 2000; Widen et al., 2000). Behavioural hearing levels for infants can be established using visual reinforcement audiometry (VRA). VRA involves reinforcing the infant’s head-turn in response to an auditory signal (usually a pure-tone or narrow band noise) and has been used reliably to establish behavioural hearing thresholds for normally developing infants as young as five months (Moore, Wilson, & Thompson, 1977). Not all infants are able to perform VRA as early as five or six months of age. For instance, infants born prematurely may exhibit developmental delay and have been reported as more likely to perform VRA at six to eight months corrected age (Moore, Thompson, & Folsom, 1992). In some cases developmental and/or visual impairment may preclude an infant from ever being able to perform the task (Cone-Wesson et al., 2000).
Objective measures of auditory function, including auditory brainstem response (ABR) and auditory steady state responses (ASSR), also known as steady state evoked potential (SSEP), are able to provide a reliable estimate of hearing levels for very young children, therefore increasing confidence in the level of residual hearing (Cone-Wesson, Dowell, Tomlin, Rance, & Ming, 2002; Rance, Dowell, Rickards, Beer, & Clark, 1998; Rance & Rickards, 2002; Rance, Rickards, Cohen, De Vidi, & Clark, 1995; Rance et al., 2005). This method, however, does not have perfect sensitivity and specificity. That is, it is possible that a child with significant hearing loss could fail to be identified as having a hearing loss. The reverse situation is also possible, where a child with normal hearing could be identified as having a hearing loss. For the purpose of assessing a child for a CI it is important to be aware of the likelihood that a child with severe or better hearing could be identified as being severe-to-profound or worse and hence considered a candidate for cochlear implantation.

A retrospective study of 108 infants and young children assessed using objective measures of auditory function was conducted by Rance et al. (1998). The authors examined the distribution of behavioural hearing thresholds in a group of children who had shown no click-evoked ABR at maximum presentation levels (100 dBnHL) and investigated the relationship between the ASSR and behavioural hearing thresholds. The authors concluded that click-ABR assessment could not differentiate between the subjects with total hearing loss and those with useful residual hearing. The correlation between ABR and behavioural threshold was poorest for the low frequencies. Seventy eight percent of the ears tested were found to have measurable hearing at 500Hz, despite absent click-ABR. In contrast, only 12% of children found to have residual hearing had absent ASSR at 500Hz. In situations where the ASSR was absent at maximum levels, 99.5% of the ears showed either a total loss or a behavioural threshold within 10 dB of that level. When an ASSR was obtained, the hearing threshold was typically within 5 dB of the ASSR threshold.
The findings of Rance et al. (1998) suggested that the ASSR has better specificity than ABR for determining level of residual hearing in young children. A few studies have raised concern regarding the use of ASSR in the neonatal period (John, Brown, Muir, & Picton, 2004; Rance & Tomlin, 2006; Rance, Tomlin, & Rickards, 2006). Rance and Tomlin (2006) conducted a longitudinal study comparing the tone-burst ABR (TB-ABR) and ASSR thresholds at 500Hz and 4kHz for 12 full-term infants at 0, 2, 4 and 6 weeks of age. ASSR thresholds were found to be more variable than TB-ABR, particularly at the neonatal measurement point and within-subject changes across the test period were observed for ASSR thresholds but not for TB-ABR. The authors concluded that for normal neonates, the TB-ABR technique may offer a more reliable basis for prediction of hearing levels than ASSR assessment because the TB-ABR is less affected by maturational development in the first weeks of life and is less variable across subjects. In another study by Rance and Tomlin (2006) it was reported that mean ASSR threshold levels decreased by approximately 10 dB between week 0 and week 6 data collection points. John et al. (2004) also concluded that comprehensive frequency-specific testing of hearing using ASSR will likely be more accurate if postponed until after the immediate neonatal period.

It is evident from the above findings that no single measure of auditory function is able to stand alone as “the” measure for determining hearing thresholds in infants. Rather a combination of objective measures (ASSR and ABR) could be used in the first few months of life to identify those children who should be referred for CI candidacy assessment followed by behavioural assessment to determine those children who should then proceed with implantation.

2.9 Measuring communication outcomes for hearing impaired children

The evaluation of language can provide a useful insight into an individual child’s skills and identify the need for remediation. Evaluating cohorts of children and reporting on
group averages can provide useful information about trends in development e.g. for children with hearing impairment. Evaluation of children with hearing impairment’s oral language is ideally comprehensive enough to capture a broad range of skills, e.g. speech production, syntax and vocabulary, while also providing a picture of development as the child matures.

Formal or standardized assessments of oral language have featured heavily in the literature describing the development of children with normal hearing and those with hearing loss. Standardized assessment will demonstrate a child’s skills compared with typically developing peers and can provide useful information for integration and inclusion. Standardized assessment may not, however, identify the specific language structures that require intervention and may not demonstrate use of language when communicating with other people (Paul, 2012).

Thoutenhoofd et al. (2005) emphasized the importance of assessing how a child is functioning and communicating “in their day-to-day lives, after implantation, rather than clinical tests” (p.243). Others have also highlighted the importance of including broader outcome measures, particularly the importance of parental report, in the assessment of outcome for children with hearing impairment (Knoors, Meuleman, & Klatter-Folmer, 2003; Lin et al., 2008). Parental report is able to provide a valuable picture of day-to-day communication and acknowledges the parent as an important source of information (Yoshinaga-Itano, 1994). Use of parental report or questionnaire does however, draw criticisms as it may be open to serious bias in unblinded studies (Wake et al., 2005). Other studies have also raised questions regarding reliability and validity of using parental report to quantify receptive language development (Thal, O’Hanlon, Clemmons, & Fralin, 1999; Tomasello & Mervis, 1994; Tomblin, Shonrock, & Hardy, 1989). Dale, Bates, Reznick, and Morisset (1989), however, felt that the advantages of parental reports outweighed the pitfalls.
Child language development is complex and multi-faceted and its evaluation should reflect this. It appears simplistic to make claims on the benefits of implantation using a single assessment tool (particularly parent questionnaire). Assessment of long term outcomes is crucial because there are precedents that children using CIs can catch up, for example see Blamey, Barry, Bow, et al. (2001). The present study will address the above mentioned issue by prospectively evaluating the oral language development of the study cohort over a 6 year period. Evaluation measures in the present study will include both parental questionnaire and standardized assessments.
3 RELEVANCE AND IMPORTANCE OF THE STUDY

The advent of newborn screening programs around the world has resulted in earlier referral of infants for diagnostic hearing assessment. This early diagnosis of hearing loss has provided families with the opportunity to access hearing technology (HAs and CIs) and early intervention services at a younger age than had occurred in the years preceding newborn hearing screening.

Previous research has suggested that age at implantation is a significant contributing variable in oral language and developmental outcomes for children with severe-to-profound hearing loss. The majority of published studies to date however, have focused on children implanted over 12 months of age and few include significant numbers of children who received an implant before 12 months of age. Many studies have also been limited in their description of outcomes, typically limiting their investigations to one or two domains of communication e.g. speech perception and/or language and failing to describe the full spectrum of oral communication. Duration of follow up is also a limitation of many studies investigating the benefits of early implantation. In order to capture the oral language capabilities of children who receive a CI at an early age, long-term follow-up and description of a broad range of skills is desirable.

There is little research that relates specifically to age at identification of children with severe-to-profound hearing loss who proceed with a cochlear implant. It is reasonable to assume that an early age of identification will result in an earlier age at implantation. For many children however, there are additional factors, including medical, audiological, funding, family and/or deaf culture issues that may result in a child not receiving a CI until they are over 12 months of age. The question therefore remains, whether early identification is a sufficient condition to promote optimum
communication development, or whether early implantation is the critical variable. It is also possible that early identification is causally linked to early implantation and is thus a necessary pre-requisite. The relationship and impact between these two factors will be explored in detail in the present study.

The first aim of this study was to describe the demographic characteristics of a cohort of 32 children who received their cochlear implant(s) before 2.5 years of age. The characteristics described included: age at hearing loss diagnosis, age at HA fitting, age at cochlear implantation, mode of communication, SES, maternal education attainment, family participation in the intervention program, family size, birth order, gender and non-verbal IQ. It was anticipated that the demographic characteristics described would not be independent of one another and the interrelationships between these factors will be investigated.

The second aim of this study was to provide a comprehensive description of the longitudinal development of speech perception, speech production and language for children who received a CI before 2.5 years of age, the period of time believed to be critical for language learning.

The final aim was to investigate the demographic factors that contributed to better speech perception, speech production and language outcomes for this group of children who received a CI at a young age.
4 STATEMENT OF THE RESEARCH QUESTIONS

This longitudinal study aimed to examine the benefits of early identification and early implantation, along with other covariates previously reported to affect outcomes for children using CIs, for children with severe-to-profound hearing loss who proceed with cochlear implantation before 2.5 years of age at The Royal Victorian Eye and Ear Hospital, Melbourne, Australia. It will be established whether age at implantation plays a key role in the development of oral language for a group of 32 children. A number of covariates commonly reported as influencing hearing impaired children’s communication outcomes will also be investigated. Standardized tests of speech perception, speech production and language outcomes have been administered at a number of intervals pre and post-implantation.

Specific hypotheses tested were:

1. That early diagnosis of hearing loss leads to younger age at cochlear implantation
2. That children (and their families) who seek a CI at a young age represent a skewed demographic from high SES areas, with highly educated mothers and families who are well engaged with their child’s intervention
3. That children implanted before 2.5 years, with no significant additional disability or cognitive delay, will develop useful open-set speech understanding irrespective of the age they received their cochlear implant
4. That age at implantation will have a significant effect on the speech production skills of children who receive a CI before 2.5 years of age, with children receiving a CI younger achieving better speech production skills
5. That children who receive a CI before 2.5 years of age will develop language at a rate comparable to peers with normal hearing
6. That age at implantation will have a significant and sustained effect on the language skills of children who receive a CI before 2.5 years of age, with those children receiving their CI younger performing better on standardized tests. Specifically, the younger a child receives a CI the more likely they will demonstrate language skills within the normative range for their hearing peers.
5 METHOD: PART 1, PARTICIPANTS

The following section of the thesis describes the study inclusion criteria and detailed demographic characteristics of the child participants.

5.1 Criteria for inclusion

The 32 participants were identified from a database of all children who received a CI through the Royal Victorian Eye and Ear Hospital Cochlear Implant Clinic, Melbourne, Australia.

In order to control for some of the known variables affecting speech and language performance of children using CIs the inclusion criteria outlined below were defined.

All participants:

- received the multichannel CI at less than 2.5 years of age
- had a congenital bilateral severe-to-profound\(^1\) sensorineural hearing loss
- demonstrated no greater than a borderline\(^2\) developmental delay
- demonstrated no aetiological or medical conditions affecting communication development
- demonstrated no specific language impairment
- used the latest speech processor and speech processing strategy
- had 20 or more active electrodes available for programming

For the purpose of this study age at hearing loss diagnosis rather than age at entry into early intervention program, was chosen as one of the potential predictive factors.

\(^1\) Best 3-frequency (500, 1 and 2kHz) pure-tone average greater than or equal to 90 dBHL for inclusion in this study

\(^2\) Child scored within two standard deviations of the mean on a standardized test of non-verbal intelligence
As described earlier, “age at intervention” encompasses several related events known to impact on communication outcome including: age of diagnosis, age of onset of training of residual hearing, age of HA fitting, age of involvement of the family and age of enrolment into an early intervention program. It was anticipated that each of these events would be highly correlated with one another; it is reasonable then to include only one or two of these events in the investigation. For the purpose of this study age at diagnosis and age at HA fitting were used.

### 5.2 Demographic Information

The demographic details regarding age at hearing loss identification (Age at ID), age at HA fitting (Age at HA), age at implantation (Age at CI), mean unaided best-ear 3-frequency pure-tone average (Best PTA), implant type (Device), aetiology, gender and choice of communication approach (Com. Mode), for the 32 participants have been provided in Table 1. Group means have been summarized in Table 2.
Table 1: Demographic details of individual participants

<table>
<thead>
<tr>
<th>Participant</th>
<th>Age at ID (yrs)</th>
<th>Age at HA (yrs)</th>
<th>Age at CI-1 (yrs)</th>
<th>Age at CI-2 (yrs)</th>
<th>Device(s) CI-1/CI-2</th>
<th>No. active electrodes CI-1/CI-2</th>
<th>Best 3FPTA (dBHL)</th>
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<sup>3</sup> Refer to explanation of categories in Table 4
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Table 2: Summary of participants

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<td>Proportion oral</td>
<td>0.72</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Family participation</td>
<td>4</td>
<td>4</td>
<td>0.80</td>
<td>2 (below av.)</td>
<td>5 (ideal)</td>
<td>A&lt;sup&gt;2&lt;/sup&gt; 1.17 ( p&lt;0.005 )</td>
</tr>
<tr>
<td>Maternal Ed</td>
<td>4</td>
<td>4</td>
<td>1.46</td>
<td>1 (Secondary)</td>
<td>6 (Post-Grad)</td>
<td>A&lt;sup&gt;2&lt;/sup&gt; 1.48 ( p&lt;0.005 )</td>
</tr>
<tr>
<td>SES</td>
<td>66.5</td>
<td>70.5</td>
<td>24.3</td>
<td>10.0</td>
<td>95.0</td>
<td>A&lt;sup&gt;2&lt;/sup&gt; 0.47 ( p=0.022 )</td>
</tr>
<tr>
<td>Proportion Male</td>
<td>0.47</td>
<td></td>
<td></td>
<td>(n=15)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Birth order</td>
<td>1.87</td>
<td>2</td>
<td>0.83</td>
<td>1</td>
<td>3</td>
<td>A&lt;sup&gt;2&lt;/sup&gt; 2.70 ( p&lt;0.005 )</td>
</tr>
<tr>
<td>Family size</td>
<td>2.31</td>
<td>2</td>
<td>0.54</td>
<td>1</td>
<td>3</td>
<td>A&lt;sup&gt;2&lt;/sup&gt; 4.94 ( p&lt;0.005 )</td>
</tr>
<tr>
<td>Non-verbal IQ</td>
<td>102</td>
<td>99</td>
<td>14</td>
<td>76</td>
<td>137</td>
<td>A&lt;sup&gt;2&lt;/sup&gt; 0.61 ( p=0.101 )</td>
</tr>
</tbody>
</table>

<sup>4</sup> Significant result suggests not normally distributed
5.2.1 Age at identification of hearing loss and age at hearing aid fitting

The mean age at identification of hearing loss for the 32 participants was 0.60 years and ranged from 0.04 to 1.83 years ($SD$ 0.56 years). Figure 1 illustrates the distribution of age at hearing loss identification for the group.

Age at HA fitting, illustrated in Figure 2, ranged from 0.13 to 1.92 years with a mean of 0.70 years ($SD$ 0.53 years). All children were fitted with HAs within 6.5 months of hearing loss diagnosis with 75% of the group being fitted within five weeks of hearing loss diagnosis. The two children (participants 10 and 18) with the longest duration between hearing loss diagnosis and HA fitting had a pattern of findings consistent with auditory neuropathy spectrum disorder (ANSD).

For three children, participants 20, 23, and 28, the exact date of HA fitting could not be obtained. Parents reported the HA fitting occurred at the same age as the age recorded for the hearing loss diagnosis and therefore duration between hearing loss diagnosis and hearing fitting has been reported as zero.
Figure 1: Age at identification of hearing loss for the 32 participants

Figure 2: Age at HA fitting for the 32 participants
5.2.2 Age at CI and duration of deafness

The mean age at cochlear implantation for the 32 children was 1.23 years with a range from 0.52 to 2.20 years (SD 0.50 years). Sixteen children received their CI(s) between six and 12 months of age, 13 received their CI(s) between 13 months and two years of age and the remaining three children received their CI(s) after two years of age. Figure 3 illustrates the distribution of age at implantation for the group.

All children were considered to have a congenital onset of hearing loss with no progression. As a result, age at cochlear implantation and duration of deafness are the same value and therefore inclusion of both variables redundant. Age at cochlear implantation is the term chosen to quantify these two variables in the present study.

![Figure 3: Age at implantation for the 32 participants](image)

5.2.3 Pre-implant residual hearing

All 32 participants underwent pre-implant audiological evaluations. Threshold data were collected objectively using ASSR and ABR and using behavioural techniques that
were appropriate for the age and developmental level of each child (e.g. VRA). All children were fitted appropriately with hearing-aids shortly after diagnosis. The pre-implant pure-tone average (PTA) using frequencies of 500, 1000 and 2000Hz in dBHL for the best hearing ear was determined for each child. Unaided hearing thresholds that exceeded the maximum level of the audiometer were assigned the value of the audiometer limit, at that frequency, plus 5 dB, to calculate the PTA (Ching, Psarros, Hill, Dillon, & Incerti, 2001). Three frequency PTA (3FPTA) for best hearing ear ranged from 90 to 125 dBHL with a mean of 111 dB HL (SD 10 dBHL).

### 5.2.4 Cochlear implant and speech processor

All children were implanted with the most up to date commercially available Nucleus® device at the time of their surgery. Only children using N24 and Freedom CIs were included in the study.

Programming the speech processor for each child required setting of a *threshold* level, the point at which the individual detects the signal two out of three times, and a *maximum comfort* level. Appropriate threshold levels were obtained for all children using VRA (Moore, Thompson, & Thompson, 1975) and/or Play Audiometry (Wilson & Thompson, 1984) depending on the age, developmental stage and response state of the child. Instructions to the child to established maximum comfort levels used language that was appropriate for each child’s comprehension and, as required, written or pictorial representations of loudness (Staller, Beiter, & Brimacombe, 1991). The maximum comfort levels were also checked by eliciting an auropalpebral reflex (eye blink in response to a loudness discomfort level) and subsequently reducing levels by approximately 30% of the electrical dynamic range (Rance & Dowell, 1997). All children attended regular otological and audiological reviews at the Cochlear Implant Clinic at The Royal Victorian Eye and Ear Hospital, Melbourne, Australia.
5.2.5 Everyday device use

Pre-operatively all children were fitted with bilateral HAs. At the time of implantation, 27 participants proceeded with a unilateral CI in the worse hearing ear. The remaining five children received simultaneous (one surgery) bilateral cochlear implants. Of the 27 children who initially proceeded with a unilateral cochlear implant, 19 subsequently received a sequential bilateral implant between the ages of 0.71 and 4.42 years. Eight children remained unilateral CI users throughout the duration of the study. One child with a unilateral CI consistently used a contralateral HA. The remaining seven children with a unilateral CI either did not use a contralateral HA or used it less than 50% of waking hours.

5.2.6 Aetiology

Of the 32 children included in the study six different aetiologies were identified as the cause of the hearing loss. Three participants had family history of hearing loss with no gene identified (Familial), seven were found to have a Connexin26 gene mutation (Connexin26), two had their hearing loss attributed to Cytomegalovirus infection (CMV), three participants had findings consistent with Auditory Neuropathy Spectrum Disorder (ANSD), one participant had Large Vestibular Aqueducts (LVAS) and the majority, 16 participants, had unknown aetiology (Unknown).

Table 3 shows the proportion of participants with each aetiology as a percentage of the total group of 32 children.

Table 3: Percentage of participants with each aetiology

<table>
<thead>
<tr>
<th>Aetiology</th>
<th>Percentage of participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Familial</td>
<td>9%</td>
</tr>
<tr>
<td>Connexin26</td>
<td>22%</td>
</tr>
<tr>
<td>Aetiology</td>
<td>Percentage of participants</td>
</tr>
<tr>
<td>-----------</td>
<td>---------------------------</td>
</tr>
<tr>
<td>CMV</td>
<td>6%</td>
</tr>
<tr>
<td>ANSD</td>
<td>9%</td>
</tr>
<tr>
<td>LVA</td>
<td>3%</td>
</tr>
<tr>
<td>Unknown</td>
<td>50%</td>
</tr>
</tbody>
</table>

### 5.2.7 Mode of communication and educational placement

Mode of communication was ranked on a six point scale as proposed by Geers and Brenner (2003). Rankings 1-3 included children who use varying degrees of sign to augment communication and have been referred to as TC throughout the study. Rankings 4-6 included children with an AO emphasis. Category descriptions are given in Table 4.

**Table 4: Categories of communication mode (Geers & Brenner, 2003)**

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Total Communication (TC) with a sign emphasis, and some periods of each day when no speech was used</td>
</tr>
<tr>
<td>2</td>
<td>TC with an equal emphasis on speech and sign</td>
</tr>
<tr>
<td>3</td>
<td>TC with a speech emphasis and some periods in each day where only speech was used</td>
</tr>
<tr>
<td>4</td>
<td>Cued Speech, which is a formal system of hand cues designed to represent the visemes of speech, thus facilitating lip-reading</td>
</tr>
<tr>
<td>5</td>
<td>Aural/Oral, (AO) where the child uses speech, lip-reading and listening throughout each day</td>
</tr>
<tr>
<td>Category</td>
<td>Description</td>
</tr>
<tr>
<td>----------</td>
<td>-------------</td>
</tr>
<tr>
<td>6</td>
<td>Auditory Verbal, (AV) where there is a de-emphasis on visual cues and the child is taught to use listening for the primary reception of speech</td>
</tr>
</tbody>
</table>

Mode of communication details were collected at each assessment interval and documented on a questionnaire used to capture family and educational characteristics of the participant (refer Appendix 3).

Due to the longitudinal nature of the current study it was anticipated that some children would change mode of communication during the course of the investigation, particularly as their oral language skills using the CI became more apparent. This was the case for only two participants, participants 14 and 16, who transitioned from Category 3 to Category 2 between the three year post-operative assessment and school entry assessment intervals.

For the purpose of statistical analysis, children were categorized into two broader categories, AO communication (Categories 4-6) or TC (Categories 1-3). The percentage of children using AO mode of communication at the time of implantation was 72%. The remaining 28% used total communication.
6 METHOD: PART 2, EXPERIMENTAL METHODS AND EQUIPMENT REQUIREMENTS

The following section describes the experimental method, test battery and equipment requirements of the study.

6.1 Assessment schedule

Each child’s speech perception, speech production and language were assessed prospectively at a number of intervals pre and post-implantation. Table 5 details the assessments and time intervals in which data was collected.

The formal assessment schedule for a child was determined by their age at the time of implantation and the appropriateness of the test material for their chronological age. For example, if a child received their CI at 2.5 years of age, the three year post-implantation and school entry assessment points would fall in the same calendar year. When this situation arose the more detailed of the two assessment points was completed i.e. school entry.

A description of each assessment is provided in the subsequent section.

Table 5: Assessment battery and schedule

<table>
<thead>
<tr>
<th>Assessment</th>
<th>Assessment interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rossetti Infant Toddler Language Scale (RI-TLS)</td>
<td>Pre-op</td>
</tr>
<tr>
<td>Preschool Language Scale (PLS-4) or Clinical Evaluation of Language Fundamentals (CELF-pre/4th Ed)</td>
<td>✔️</td>
</tr>
<tr>
<td>Assessment</td>
<td>Pre-op</td>
</tr>
<tr>
<td>----------------------------------------------------------------------------</td>
<td>--------</td>
</tr>
<tr>
<td>Peabody Picture Vocabulary Test – 3rd or 4th Ed (PPVT-III &amp; IV)</td>
<td>✓</td>
</tr>
<tr>
<td>Diagnostic Evaluation of Articulation and Phonology (DEAP)</td>
<td></td>
</tr>
<tr>
<td>Family and educational characteristics questionnaire</td>
<td>✓</td>
</tr>
<tr>
<td>Categories of Audiology Performance</td>
<td>✓</td>
</tr>
<tr>
<td>CNC open-set words in quiet, auditory alone – everyday listening condition</td>
<td></td>
</tr>
</tbody>
</table>

Test materials were administered and scored by qualified speech pathologists and/or audiologists with experience working with hearing impaired children using CIs in a quiet clinical environment or sound proof booth.

### 6.2 Assessments

#### 6.2.1 Speech perception

#### 6.2.1.1 Categories of Auditory Performance

The Categories of Auditory Performance (CAP) (Archbold et al., 1995) is a tool used to assess the auditory perception for children who are unable to complete the formal tests of speech perception (too young to undergo formal evaluation, do not have verbal skills, do not understand the task, or do not have cognitive prerequisites of sustained attention and memory, cannot imitate-on-demand, cannot select-on-demand). A key advantage of the CAP is that it allows the categorization of all children irrespective of their skill level. The CAP is an eight-point (0-7) hierarchical
scale of auditory performance, ranging from no awareness of environmental sound to use of the telephone with a known speaker. Assignment of one auditory perception category assumes mastery of preceding levels. The CAP has been demonstrated to have very high inter-user reliability (Archbold, Lutman, & Nikolopoulos, 1998). An experienced clinician, familiar with the child, rated the child’s auditory perception using the eight categories described in Table 6. Ratings were collected pre-operatively and at one, two and three years post-operatively. All children were capable of formal speech perception testing by the final, school entry, assessment interval; therefore the use of the CAP was no longer required.

**Table 6: The Categories of Auditory Performance (Archbold et al., 1995)**

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
</table>
| 0        | **Displays no awareness of environmental sounds**  
Wearing appropriate aids with good earmoulds, the child does not alert spontaneously to any environmental sounds. Nor has the child been reported to alert to environmental sounds. |
| 1        | **Awareness of environmental sounds**  
The child has been observed to make a spontaneous reaction to about half a dozen different environmental sounds (at home, at school, in the clinic or outdoors). The reaction need not indicate that the child recognises the sound, only that he or she has detected it. |
| 2        | **Responds to speech sounds**  
The child will obey a simple command, such as the instruction ‘Go’ to perform an action such as rolling a ball at a skittle, when delivered in a normal conversational level at a distance of 1-2 feet. |
<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
</table>
| 3        | Recognizes environmental sounds  
The child has been observed to identify a range of about half a dozen environmental sounds consistently in everyday life (e.g. doorbell, telephone, parent’s voice, traffic etc.). Observers are confident that the child is monitoring his or her environment via audition. |
| 4        | Discriminates at least two speech sounds  
The child can discriminate consistently any combination of two of Lings five sounds (/s/, /sh/, /ee/, /oo/, /aa/) presented with live voice at conversational level without lip-reading. |
| 5        | Understanding common phrases without lip-reading  
The child is able to identify common phrases in a familiar constraining context. For example, the child can perform the IOWA Closed-Set Sentence Test at Level A; or the child can identify simple, familiar questions in a known context (e.g. ‘What’s your name?’, ‘Where is mummy?’, ‘How old are you?’); or the child can identify a picture correctly from a limited set of when the picture is described verbally. |
| 6        | Understands conversation without lip-reading with a familiar talker  
The child can carry out a simple unscripted conversation with a familiar talker (e.g. parent or teacher) without lip-reading in a quiet setting. The child must be able to respond correctly to simple questions without interaction breaking down. |
| 7        | Can use the telephone with a familiar talker  
The child can sustain a simple unscripted conversation on the telephone with a familiar talker. The child must be able to respond correctly to simple questions without interaction breaking down. |
6.2.1.2 Monosyllabic (Consonant-Nucleus-Consonant) words

The Consonant-Nucleus-Consonant (CNC) (Peterson & Lehiste, 1962) test is a phonetically balanced test used to assess open-set word performance. The subject is expected to identify and repeat a word. The CNC battery consists of ten different lists and each list contains 50 words and 150 phonemes. Results are reported as percentage of phonemes correct and percentage of words correct.

Speech perception material was presented audition alone via live-voice or from a pre-recorded CD presented from a loudspeaker. In the live-voice condition, the procedure required clinicians to present the test materials from a distance of approximately one meter and at an intensity of 65 dBA, monitored using a sound level meter, in a sound proof booth. No visual cues were available. All recorded material was presented at a level of 70 dB SPL(RMS). In both the recorded and live conditions, the clinician presenting the material or loudspeaker was positioned at 0° azimuth to the child’s head. Participants were assessed in their everyday listening condition. Children’s verbal responses were scored live by an experienced audiologist or speech pathologist. The aim was to assess all children in the recorded condition. However, not all children could be engaged to complete recorded testing, e.g. co-operation of the child was at risk. In this situation, individual clinicians used their discretion in deciding whether to test children in the live or recorded condition. Live voice presentation allowed the clinician to engage the child more readily by varying intonation and providing on going encouragement to respond/imitate. Live voice presentation was more commonly used with the younger children in the study and those unfamiliar with formal speech perception testing. Speech perception performance on a monosyllabic word test for children, using cochlear implants, in a (controlled) live-voice condition versus presented using a loudspeaker has been shown to be significantly different (Dettman, 2016, personal communication, March 31). Dettman (2016, personal communication, March 31) provided a predictive function which yielded the pre-recorded score based on the live-voice score (refer to
Appendix 1). The predictive function provided by Dettman (2016, personal communication, March 31) was applied to the live-voice scores obtained in the present study.

Formal speech perception testing was completed at the school entry assessment interval.

6.2.2 Speech production

6.2.2.1 Diagnostic Evaluation of Articulation and Phonology (DEAP)

The DEAP is designed to identify the presence of a delay in articulation or phonology for children aged three years to six years 11 months (Dodd, Hua, Crosbie, Holm, & Ozanne, 2002). The test requires the child to orally label a series of 50 pictures.

The DEAP was administered to each child individually by a qualified speech pathologist in a quiet clinical environment. The subject’s productions were transcribed using broad phonetic transcription in accordance with the International Phonetic Alphabet (International Phonetic Association, 1999). The broad transcriptions were then entered into a computer based analysis programme, Computer Assisted Speech and Language Analysis (CASALA) (Serry, Blamey, Spain, & James, 1997). The CASALA program compares the child’s production of each word in the DEAP against an existing file of correct phonetic alternatives to derive a percentage correct vowel, consonant and total phoneme score. Any errors are labelled and analysed in terms of the phonological processes involved. The phonological processes used in the development of the CASALA program have been drawn from a number of different works (Grunwell, 1982; Ingram, 1976; Khan, 1982; Shriberg & Kwiatkowski, 1980; Weiner, 1979). CASALA also computes a percentage correct score for individual monophthongs, diphthongs, and consonants. It also provides a total score for all vowels, consonants, consonant clusters, and words produced correctly throughout a
sample. For the purpose of this study results of interest are: percentage of vowels, consonants and phonemes correct and list of phonological processes.

Percentage of vowels, consonants and phonemes correct were converted to standard score using the DEAP examiner’s manual (Dodd et al., 2002). For children older than the upper limit of the assessment, their standard score was taken to be the same as the children in the oldest available age range. The standard score for the DEAP subtests has a mean of 10 and standard deviation of three. Standard scores between seven and 13 are within the typical range for age matched peers.

Results were further analysed to produce a percentage of phonemes correct (PCC) using the Phonology section of the DEAP. For each participant, the PPC was considered in relation to the expected PCC (50th percentile) for a typically developing child of equivalent age. For children older than the upper limit of the assessment, their expected PPC was taken to be the same as the children in the oldest available age range.

An analysis of phonological processes was conducted for each participant using the relative index of unintelligibility (RIU), as determined by CASALA. RIU is calculated by dividing the number of observed incidences of a particular phonological process by the total number of words in the sample (Crary & Comeau, 1981). For example, an RIU of 0.1 corresponds to five errors in every 50 words. RIU allows the relative impact of a process on the child’s intelligibility to be quantified. If, for example, a process occurred on the sound ‘zh’ as in ‘vision’, it would be less likely to impact on a child’s overall intelligibility, as ‘zh’ is an infrequently used consonant in English. In contrast, if a process occurred on the sound ‘n’ this would be likely to have a much greater impact on the child’s intelligibility because ‘n’ is one of the most frequently occurring consonants in English (Mines, Hanson, & Shoup, 1978).
Phonological processes were categorized as developmental or non-developmental as defined in Flipsen & Parker (2008). Categorization of the 41 phonological processes, specified by the CASALA program, are shown in Appendix 4. Outcomes for each subject are described as total number of phonological processes (where any RIU was >0.00), total number of processes where RIU ≥0.1, number of developmental processes where RIU ≥0.1 and number of non-developmental processes where RIU ≥0.1.

### 6.2.3 Language

#### 6.2.3.1 Rossetti Infant Toddler Language Scale (RI-TLS)

The RI-TLS (Rossetti, 1991) assesses six areas of development, which relate to communication and language in children from birth to three years of age. These subscales include: (1) Interaction and Attachment (relationships with others), (2) Pragmatics (the way we use language), (3) Gesture (expression with the hands or face), (4) Play, (5) Language Comprehension, (6) Language Expression.

The scale is scored based on a combination of parent interview, direct observation of the child during play and elicitation procedures. Each skill is scored in two ways: age range mastered and maximum age for emerging skills. The age range mastered indicates that the child demonstrated all of the skills described for this age. The maximum age for emerging skills describes the upper limit of any emerging skills demonstrated by the child.

The RI-TLS was administered once pre-operatively and at 12 months post-implantation. The repeated administration of the test allowed for a slope or rate of growth to be calculated for the language comprehension and language expression subscales.
6.2.3.2 Preschool Language Scale – Fourth edition (PLS-4)

The PLS-4 (Zimmerman, Steiner, & Pond, 2002) is a language evaluation appropriate for children from birth through to six years 11 months of age. This assessment evaluates comprehension and use of basic vocabulary, concepts, grammatical markers, and sentence structures. It is comprised of two subscales, the Auditory Comprehension Subscale which evaluates the language a child can understand and the Expressive Communication Subscale which evaluates how well a child communicates with others. A raw score, standard score and age equivalent are generated for each subscale as well as for a Total Language score. Standard scores between 85-115 are within normal limits for hearing children. Age equivalent provides the chronological age at which the child tested is performing at and enables language delay to be quantified e.g. if a child aged 7;6 has an age equivalent of 6;0 that child has a language delay of 18 months. PLS-4 has been norm referenced on a large group of children (>1500 children).

The PLS-4 was administered to each child individually at the school entry assessment point by a qualified speech pathologist in a quiet clinical environment.

6.2.3.3 Clinical Evaluation of Language Fundamentals – Preschool and Fourth Edition (CELF-P and CELF-4)

The Clinical Evaluation of Language Fundamentals (Preschool and 4\textsuperscript{th} edition) was used to evaluate receptive and expressive spoken language. The Preschool Edition (CELF-P) (Wiig, Secord, & Semel, 1992) is a standardized measure of receptive and expressive language skills suitable for children aged three to six years. The Clinical Evaluation of Language Fundamentals Fourth Edition (CELF-4) (Semel, Wiig, & Secord, 2003) is suitable for children aged five to 21 years. CELF-4 overlaps with the CELF-P for ages five and six years. The CELF-P includes six subtests: three designed to assess receptive language skills and three for expressive skills. The CELF-4
includes 18 subtests organized into four levels of testing that address language content, structure, and use. Standard scores, referred to as scaled scores, are provided for each subtest, where 10 is the mean and 7-13 is considered the range of average. The receptive language index for both editions is a cumulative measure of performance on two or three subtests designed to assess receptive aspects of language including comprehension and listening. The expressive language index is a cumulative measure of performance on three subtests designed to best probe expressive aspects of language including oral language expression. Both editions are norm referenced on large groups of children (>1500 in the case of CELF-P and >4500 in the case of CELF-4).

A raw score, standard score, and age equivalent were generated for the receptive and expressive indexes as well as for a total/core language score. Standard scores between 85-115 are within normal limits for hearing children.

CELF-P and/or CELF-4 were administered at the school entry assessment point by a qualified speech pathologist in a quiet clinical environment for two participants who did not complete the PLS.

Results from CELF-P, CELF-4 and PLS obtained at the school entry assessment interval have been combined in the analysis.

6.2.3.4 Peabody Picture Vocabulary Test – Third Edition (PPVT-III) and Fourth Edition (PPVT-4)

The PPVT-III (Dunn & Dunn, 1997) and PPVT-4 (Dunn & Dunn, 2007) were used as a measure of single-word receptive vocabulary and are suitable for children from age two years and six months. PPVT is a norm-referenced test that allows comparison of an individual’s performance with that of a well-defined reference group of American children with normal hearing and English as their primary language. Due to the
longitudinal nature of this study, PPVT-III (Forms 3 A & B) and PPVT-4 (Forms 4 A & B) editions were used. The two editions are highly correlated ($r=0.84$) (Dunn & Dunn, 2007) therefore results from each edition have been combined in the analysis. Each edition and form has approximately 204 test items arranged in order of increasing difficulty.

The PPVT requires that the subject choose from a set of four pictures in response to a question such as “point to cat”. No feedback is given to the subject as to the correctness of the response. The basal level is established (set of 12 items with one or no errors) and the test proceeds until the child reaches a ceiling level (eight incorrect responses within a set of 12 items). The subject’s raw score is calculated by subtracting the total number of errors occurring between the basal and ceiling levels. Raw scores were expressed in two ways: as a standard score and as an equivalent age.

The PPVT was administered to each child individually by a qualified speech pathologist in a quiet clinical environment.

The PPVT was administered up to four times, depending on the age the child was implanted (for example, if the child was implanted at eight months of age, it would not be appropriate to administer the PPVT at the one year post-implantation assessment point). As for the RI-TLS, the repeated administration of the PPVT allowed for a slope or rate of growth to be calculated.

### 6.2.4 Cognitive and general development

All participants were screened for cognitive and general development by qualified speech pathologists experienced at working with children with hearing impairment. If concern was raised by either the child’s parents or speech pathologist, a referral was made for educational psychology evaluation at any point during the study. For the
The majority of participants’ the assessment was completed just prior to entering primary/elementary school. An educational psychologist with experience working with children with hearing impairment administered non-verbal intellectual measures or developmental assessments. The psychologist selected a test battery most appropriate for the child, depending on his/her age at the time of testing or information desired for educational planning. The assessment tools included the Wechsler Preschool & Primary Scale of Intelligence (WPPSI-III) (Weshsler, 2002) and Wechsler Nonverbal Scale of Ability (WNV) (Wechsler & Naglieri, 2006).

Eight children were assessed using the WPPSI-III and the remaining 24 were assessed using the WNV. Performance scale scores on the WPPSI-III and full scale scores from the WNV were combined in the analyses.

6.2.4.1 Wechsler Preschool & Primary Scale of Intelligence (WPPSI-III)

The WPPSI-III is an intelligence test designed for children ages two years six months to seven years three months. It provides subtest and composite scores that represent intellectual functioning in verbal and performance cognitive domains, as well as providing a composite score that represents a child’s general intellectual ability (i.e., Full Scale IQ).

Composite scores have a mean of 100 and a standard deviation of 15. For composite scores, below 70 is Extremely Low, 70-79 is Borderline, 80-89 is Low Average, 90-109 is Average, 110-119 is High Average, 120 and above is Superior.

The performance scale score was used for the purpose of this study as it is not dependent on verbal skills.
6.2.4.2 Wechsler Nonverbal Scale of Ability (WNV)

The Wechsler Nonverbal Scale of Ability (WNV) is an individually administered clinical instrument designed to measure the general cognitive ability of examinees aged four years through to 21 years 11 months. Pictorial directions rather than verbal instructions are used to administer this assessment. This makes the WNV particularly useful for individuals with hearing loss. A Full Scale score is derived from the examinees performance on four subtests. For examinees aged four years to seven years 11 months the Matrices, Coding, Object Assembly, and Recognition subtests are administered. For examinees aged eight years to 21 years 11 months the Matrices, Coding, Spatial Span, and Picture Arrangement subtests are administered.

The child’s full scale score was used in the analysis. Full scale scores have a mean of 100 and a standard deviation of 15. Full scale scores below 70 are defined as Extremely Low, 70-79 is Borderline, 80-89 is Low Average, 90-109 is Average, 110-119 is High Average and greater than 120 is Superior.

6.2.5 Family participation rating

A family participation rating scale was adapted from that used by Moeller (2000). The rating scale was used to characterize the quality of the family participation in the CI intervention program. Parent participation was rated by two clinicians most familiar with the participant and their family. Ratings were made independently by the two clinicians. Each family received a rating from one to five which reflected their participation in the CI program. Ratings were aimed to encompass issues such as adjustment to the child’s hearing loss, session participation and effectiveness of communication with the child. Clinicians providing the ratings were given specific descriptions of characteristics representing each category (refer to Appendix 2). Scores were assigned as follows: 1=limited participation, 2=below average participation, 3=average participation, 4=good participation and 5=ideal participation.
Clinicians were also asked to rate their confidence in their ratings, options were good, okay or questionable. Any ratings judged as questionable were excluded. A formula was applied to average the ratings of the two clinicians while taking into account the confidence of the clinician, resulting in a weighted average for each child at each assessment point.

**Equation 1: Calculation of weighted average for family participation rating**

\[
\text{Weighted average} = \frac{(\text{rating}_1 \times \text{confidence}_1 + \text{rating}_2 \times \text{confidence}_2)}{\text{confidence}_1 + \text{confidence}_2}
\]

6.2.6 Family characteristics

A questionnaire designed to capture key features of the child’s education and family characteristics was developed based on that used by Geers and Brenner (2003). A copy of the questionnaire can be found in Appendix 3:

Information captured on the questionnaire was used to describe the demographics of the participants and their family e.g. position of the child in the family.

6.2.7 Socioeconomic status (SES)

Data was obtained from the 2006 Australian Bureau of Statistics Census database to categorize SES (Australian Bureau of Statistics, 2008). Census data provides median family income by postcode/ZIP code. The participant’s postcode at the time of implantation was used to estimate family income.

The Index of Relative Socioeconomic Advantage and Disadvantage (IRSAD) ranks areas on a continuum of social and economic advantage to disadvantage (SEIFA) across Australia. Lower scores or percentiles (e.g. 0-10) represented being relatively disadvantaged, while higher scores (e.g. 90-100) indicated the reverse when compared against the mean SEIFA score.
Using this method of determining SES has its limitations because it only provides an estimate of family income and the reality for some families may be different. The advantage of this indirect method of categorizing SES is that it ensures a measure of SES will be available for all children in the study and eliminates the issue of non-responses that would be expected with a questionnaire asking about income. In addition, it avoids the potential bias posed by some questions that parents may be reluctant to answer.

### 6.2.8 Maternal Education

Maternal education for each participant was categorized according the Australian Standard Classification of Education, 2001 (Australian Bureau of Statistics, 2001). Educational attainment codes applied are outlined in Table 7.

**Table 7: Level of Education - Broad Levels (Australian Bureau of Statistics, 2001)**

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Postgraduate Degree Level</td>
</tr>
<tr>
<td>2</td>
<td>Graduate Diploma and Graduate Certificate Level</td>
</tr>
<tr>
<td>3</td>
<td>Bachelor Degree Level</td>
</tr>
<tr>
<td>4</td>
<td>Advanced Diploma and Diploma Level</td>
</tr>
<tr>
<td>5</td>
<td>Certificate Level</td>
</tr>
<tr>
<td>6</td>
<td>Secondary Education</td>
</tr>
<tr>
<td>7</td>
<td>Primary Education</td>
</tr>
<tr>
<td>8</td>
<td>Pre-primary Education</td>
</tr>
<tr>
<td>9</td>
<td>Other Education</td>
</tr>
</tbody>
</table>
6.3 Statistical analysis

Throughout this study, the 32 children using CIs were compared to typically developing hearing peers. When normative samples are available from standardized tests, standard scores have been used. Standard scores were used to compare one subject’s performance on a test to the performance of typically developing peers. Standard scores reveal whether a child’s scores are above average, average, or below average compared to peers. They also enable comparison of a child’s scores on different types of tests. The test developers have attempted to obtain normative samples that are representative of the population in general. Using standard scores controls for differences in age among the study participants and was therefore considered ideal for this analysis.

Normative data were not available for all measures used in this study, so it was necessary to use raw scores and or age equivalents to represent abilities. In these instances, the 32 participants were compared against published outcomes for hearing impaired children and typically developing children where available.

Statistical analysis was conducted using Minitab statistical software version 16 (Ryan, Joiner, & Cryer, 2012; Ryan, Joiner, & Ryan, 1994).

Distributions for demographic factors were tested for normality using the Anderson-Darling Normality Test. A significant result ($p<0.05$) suggested that the distribution was not normal.
7 RESULTS: PREDICTIVE FACTORS

This section aims to describe the family and child characteristics considered to be potential predictor variables influencing speech perception, speech production and language outcomes for the 32 participants included in this study. The association between demographic details defined in chapter 6 and family and child characteristics are also described.

7.1 Family/child characteristics

7.1.1 Socioeconomic status (SES)

SES, quantified as percentiles according to the Australian Bureau of Statistics Index of Relative Socioeconomic Advantage and Disadvantage, ranged from percentile 10 to 95. Lower scores (e.g. 10) represented being relative disadvantage. The mean percentile of the group was 67. SES percentile was not normally distributed with the distribution of the participant group skewed towards higher SES (refer Figure 4).
7.1.2 Family participation rating

A family participation rating adapted from Moeller (2000) was used to characterize the quality of the family participation in the CI intervention program. Ratings were aimed to encompass issues such as adjustment to the child’s hearing loss, session participation and effectiveness of communication with the child (refer to Appendix 2). Ratings were assigned as follows: 1=limited participation, 2=below average participation, 3=average participation, 4=good participation and 5=ideal participation.

Mean family participation rating was 4.13 (good participation) with a range from two (below average) to five (ideal participation). The distribution of family participation rating is illustrated in Figure 5. No family was rated as having “limited participation” (rating 1).
The distribution of family participation rating was not normally distributed. The distribution was skewed towards higher family participation ratings which suggested that parents of children in the present study were more likely to be rated as being ‘good’ or ‘ideal’ participators in the intervention program.

### 7.1.3 Maternal Education

Maternal education ranged from secondary education (category 6) to postgraduate education (category 1). Six percent of mothers had only secondary education and 31% had a post graduate education (refer to Figure 6).

The distribution of maternal education was not normally distributed. The distribution was skewed towards higher levels of education which suggested that a large proportion of participants in this study had mothers who had completed a bachelor degree or higher.
7.1.4 Family size and birth order

Family size was quantified as number of children in the family (including the participant) and ranged from one (only child) to three. Mean family size was 2.3 children. Details are provided in Table 8.

Birth order was used to describe the position of the participant amongst their siblings, if any. Birth order ranged from first child (first born) to third child with a mean of 1.9 and median of two. Details are provided in Table 8.

Table 8: Family size and birth order

<table>
<thead>
<tr>
<th>Family Size</th>
<th>No. of Participants</th>
<th>Birth Order</th>
<th>No. of Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1&lt;sup&gt;st&lt;/sup&gt;</td>
<td>13</td>
</tr>
<tr>
<td>2</td>
<td>20</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt;</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>11</td>
<td>3&lt;sup&gt;rd&lt;/sup&gt;</td>
<td>9</td>
</tr>
</tbody>
</table>
7.1.5 Gender

The participant group was close to being gender balanced with 17 (53%) of the 32 children in the study being female.

7.1.6 Non-verbal intelligence

The aim was to measure the participant’s non-verbal intelligence (IQ) close to the time the child entered primary/elementary school. Mean age at the time of testing was 6.3 years. One participant was assessed at 3.4 years as the clinical need arose and one participant was assessed at a considerably older age (14.5 years) due to the inability of the family to attend the assessment at an earlier stage. The remaining 30 children were assessed between 3.8 and 10 years of age.

Non-verbal IQ was reported as a performance scale score. Mean performance scale score for the group was 101.5 with a range of 76 to 137. Non-verbal IQ for the participant group was normally distributed (refer to Figure 7).

![Non-verbal IQ](image)

**Figure 7: Non-verbal IQ for the 32 participants**
7.2 Relationship between factors being investigated/potential predictive factors

Correlation analysis was completed on all demographic and potential predictor variables to determine significant relationships between factors (refer to Appendix 5).

Age at identification, age at HA fitting and age at cochlear implantation were all significantly correlated with one another, which suggested that earlier age at identification of hearing loss was associated with earlier HA fitting and in most cases earlier implantation. These relationships are illustrated in Figure 8 and Figure 9.

All children were fitted with HAs within 6.5 months of hearing loss diagnosis and 75% of the group were fitted within five weeks of diagnosis. The two children (participants 10 and 18) with the longest duration between diagnosis and HA fitting had hearing loss consistent with ANSD.

![Relationship between age at hearing loss identification and age at HA fitting for the 32 participants. The two participants (10 and 18) with the longest duration between diagnosis and HA fitting had hearing loss consistent with ANSD.](image)
longest duration between hearing loss diagnosis and HA fitting are indicated by participant number.

Time between hearing loss diagnosis and receiving a cochlear implant(s) varied from 2.5 months to two years and there was a very strong and highly significant correlation ($r=0.785, p<0.001$). Of the two children (participants 16 and 18) with the longest duration between diagnosis and implantation, participant 18 had hearing loss findings consistent with ANSD, which had also delayed the participants’ HA fitting. There was no clear explanation for the long duration between hearing loss diagnosis and implantation for participant 16. Participant 16 was fitted with HAs within 4 weeks of hearing loss diagnosis, was from a family rated as having average participation in the intervention program, had a mother with a post-graduate qualification and was from an above average SES area.

![Figure 9: Relationship between age at hearing loss identification and age at implantation for the 32 participants.](image)

The two participants (16 and 18) with the
longest duration between hearing loss diagnosis and cochlear implantation are indicated by participant number.

Family participation rating was negatively correlated with age at cochlear implantation ($r=-0.415$, $p=0.018$), but not correlated with age at identification ($p=0.117$) or age at HA ($p=0.169$). This suggested that children in families rated as more highly engaged with their child’s intervention proceeded with a CI(s) at a younger age (see Figure 10).

![Figure 10: Relationship between age at implantation and family participation rating for the 32 participants](image)

SES was positively correlated with mode of communication ($r=0.55$, $p=0.002$), which suggested that children from higher SES backgrounds were more likely to be in AO educational settings. The relationship is illustrated in Figure 11.
Figure 11: Relationship between mode of communication and SES. Box represents middle 50% of scores with the median intersecting the box. Whiskers represent the range of scores.

Family size was negatively correlated with age at hearing loss identification ($r= -0.428$, $p=0.015$), age at HA fitting ($r= -0.39$, $p=0.027$) and age at implantation ($r= -0.354$, $p=0.047$). Families with larger numbers of children were more likely to have a child with a younger age at diagnosis which was associated with earlier HA fitting and younger age at implantation.

Family size had a significant weak correlation with mode of communication ($r=0.371$, $p=0.036$), which suggest that larger families were more likely to choose an AO mode of communication.

Family size was also correlated with birth order ($r=0.597$, $p<0.001$).
Gender was correlated with family participation rating \((r=0.412, p=0.019)\). This finding suggested that parents of female participants were rated as more highly involved in their child’s intervention.
8 RESULTS – OUTCOME MEASURES

The subsequent section aims to describe the longitudinal speech perception, speech production and language outcomes for the 32 participants. The degree of association between the demographic factors, and potential predictor variables and oral communication outcomes are described. Finally the relationship between the outcomes measures is detailed.

8.1 Speech perception

8.1.1 Categories of auditory performance

There was a progression in the sophistication of the individual participants auditory skills over time (see Figure 12). Figure 13 shows the median CAP score over time for the group.

Pre-operatively the majority of children (n=24) achieved a CAP score of zero, the remaining eight children had achieved a CAP score of one. The greatest increase in CAP score was made within the first 12 months post-implantation, where all children improved an average of four categories (highest score was seven and lowest score was five). By 24 months post-implantation 81% of children had achieved a CAP score of six. By 36 months post-implantation, 87.5% of children had achieved a CAP score of seven, the highest level achievable on this measure. Of those children who did not obtain a score of seven at 36 months post-implantation, one achieved CAP score of five and the remaining three children achieved CAP score of six.
Figure 12: Individual CAP score over time for the 32 participants. Each line represents an individual participant. Participant number is shown for the four participants who did not reach a CAP score of seven by 36 month post-implantation.
Figure 13: Median CAP score over time for the 32 participants. Whisker shows 95% confidence interval for the median. Asterisks represent individual participants considered outliers.

Chronological age was not correlated with CAP score at any of the intervals of administration.

Pre-operative CAP score was significantly correlated with pre-operative best 3FPTA ($r=-0.587$, $p<0.001$). Regression analysis revealed that PTA explained 34.5% of the variance.

The CAP score at 12 months post-implantation was significantly correlated with parent participation rating ($r=0.350$, $p=0.49$), maternal education ($r=-0.408$, $p=0.021$) and gender ($r=0.368$, $p=0.038$). Correlations between these factors made it problematic to determine causal relationships.
The CAP score at 24 months and 36 months post-implantation were significantly correlated with family participation rating ($r=0.428$, $p=0.014$ and $r=0.467$, $p=0.007$) and gender ($r=0.465$, $p=0.007$ and $r=0.431$, $p=0.014$), suggesting that female participants and children from families rated as having higher family participation achieved higher CAP scores at these two time intervals. Regression analysis suggested that 18.36% of the variance was explained by family participation rating at 24 months post-implantation and 21.76% explained by the rating at 36 months post-implantation. Family participation and gender were not combined in multiple regression analysis due to their significant correlation with one another.

### 8.1.2 Open-set word perception

Children completed speech perception assessments in their everyday listening condition. For 23 participants this was bilateral cochlear implants, for eight participants this was unilateral CI and for one participant this was CI combined with contralateral HA.

Presentation using standardized recordings via a loudspeaker in a sound treated room was always the goal, however, 10 children could not be engaged to complete recorded testing, e.g. co-operation of the child was at risk. Contingency of live voice auditory alone testing was used for these 10 children. Speech perception performance on a monosyllabic word test for children, using CIs, in a (controlled) live-voice condition versus presented using a loudspeaker has been shown to be significantly different (Dettman, 2016, personal communication, March 31). Dettman (2016, personal communication, March 31) provided a predictive function which yielded the pre-recorded score based on the live-voice score for both phoneme and word scores (refer to Appendix 1). The predictive function provided by Dettman (2016, personal communication, March 31) was applied to the live-voice scores obtained. Appendix 6 provides details of the participant’s raw scores and predicted pre-recorded scores using the predictive function outlined by Dettman (2016, personal communication, March 31).
March 31). Results for presentation via a loudspeaker and the predicted pre-recorded (adjusted live-voice) scores have been combined in the analysis.

Mean chronological age at the time of testing was 5.6 years (range 4.1-7.4 yrs). Mean CI experience was 4.2 years (range 2.9-6.6 yrs).

Figure 14 illustrates the monosyllabic word and phoneme scores for all participants as assessed when they entered primary/elementary school. Participants are ordered from lowest to highest score based on their combined word and phoneme score. Phoneme scores ranged from 49% to 98% with a group mean of 81%. Word scores ranged from 10% to 96% with a group mean of 56%.

Phoneme score was significantly correlated with family participation rating ($r=0.639, p<0.001$) and mode of communication ($r=0.362, p=0.42$), suggesting that higher family participation rating and enrollment in an education setting with an emphasis on AO communication was associated with better speech perception. Mode of communication was not significant in the multiple regression analysis so was removed as a factor in further analysis. Regression analysis suggested that 38.81% of the variance in phoneme score could be explained by family participation rating. This relationship is illustrated in Figure 15.

Word score was significantly correlated family participation rating ($r=0.598, p<0.001$) and non-verbal IQ ($r=0.353, p=0.047$), suggesting that children from families with a higher family participation rating and higher non-verbal IQ scored higher for word score. Non-verbal IQ was not significant in the multiple regression analysis so was removed as a factor in further analysis. Regression analysis suggested that 37.5% of the variance in word score could be explained by family participation.
Figure 14: Monosyllabic words, scored for words and phonemes correct, presented audition alone for the 32 participants. Participants ordered from lowest to highest score. Word score is represented by the red/left bar and phonemes are represented by the right/blue bar. Mean word score for the participants was 56% and mean phoneme score was 81%.
Figure 15: Relationship between phoneme score and family participation rating for the 32 participants

8.2 Speech production

8.2.1 Phonetic Accuracy

Speech production skills for all 32 children were assessed using the Phonology subtest of the Diagnostic Evaluation of Articulation and Phonology. Thirty children were assessed around the time they entered primary/elementary school. The two remaining children, who were unable to attend the evaluation around the time of school entry, were assessed at chronological ages 7.2 years and 8.6 years. Mean age at testing for the whole group was 5.6 years (SD 0.75 yrs, range 4.4–8.6 yrs).

Mean standard score for vowels, consonants and phonemes correct are shown in Table 9. There was no significant difference between performance for vowels compared to consonants ($t=0.38$, $p=0.707$). A standard score between seven and 13 is considered to be within the typical range. Mean score for vowels, consonants and
phonemes was below the typical range for the participant group (refer to Figure 16). Thirty eight percent of the group were performing within the typical range for vowels correct, 34% were within the typical range for consonants correct and 47% of the group were performing within the typical range for phonemes correct.

Table 9: Mean, standard deviation and range of scores for vowels, consonants and phonemes correct

<table>
<thead>
<tr>
<th>Speech Production Outcome</th>
<th>Typical range (norms)</th>
<th>Standard Score</th>
<th>Standard Deviation</th>
<th>Participant range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vowels</td>
<td>7-13</td>
<td>5.81</td>
<td>2.94</td>
<td>3-10</td>
</tr>
<tr>
<td>Consonants</td>
<td>7-13</td>
<td>5.65</td>
<td>2.98</td>
<td>3-13</td>
</tr>
<tr>
<td>Phonemes</td>
<td>7-13</td>
<td>6.09</td>
<td>3.03</td>
<td>3-13</td>
</tr>
</tbody>
</table>

Figure 16: Mean standard score for Vowels, Consonants and Phonemes correct for the 32 participants. Error bars are one standard error from the mean.
Scores above the dashed line would be within the typical range for hearing children (score of 7-13)

Vowel, consonant and phoneme scores were all correlated with age at identification ($r=-0.395$, $p=0.025$, $r=-0.388$, $p=0.028$ and $r=-0.371$, $p=0.036$), age at HA ($r=-0.370$, $p=0.037$, $r=-0.414$, $p=0.018$ and $r=-0.391$, $p=0.027$) and non-verbal IQ ($r=0.439$, $p=0.012$, $r=0.493$, $p=0.004$ and $r=0.508$, $p=0.003$). Vowel scores were also correlated with age at CI ($r=-0.363$, $p=0.041$), mode of communication ($r=0.390$, $p=0.027$), family participation rating ($r=0.401$, $p=0.023$) and best 3FPTA ($r=0.364$, $p=0.041$). Phoneme scores were also correlated with family participation rating ($r=0.401$, $p=0.023$).

For vowels, age at cochlear implantation and family participation were not found to be significant when included in separate multiple regression analyses with mode of communication, best 3FPTA and non-verbal IQ. Just over forty six percent (46.4%) of the variance in vowel score could be explained by mode of communication (15.2%), best 3FPTA (11.1%) and non-verbal IQ (20.1%).

For consonants, age at cochlear implantation was not significant in multiple regression analysis. Non-verbal IQ alone explained 24.3% of the variance in consonant score.

For phonemes, age at cochlear implantation and family participation rating were not significant when included in separate multiple regression analysis with non-verbal IQ. Non-verbal IQ alone explained 25.8% of the variance in phoneme score.

### 8.2.2 Percentage of expected phoneme score

Figure 17 illustrates the percentage of expected phonemes correct for the 32 participants. Results are shown as a percentage of expected score for the participant’s chronological age. For example, participant 10 was five years and four months at the
time of testing. A typically developing child of this age performing on the 50th percentile would be expected to achieve 97% of phonemes correct. Participant 10 scored 86% phonemes correct which results in a percentage of the expected score of 89%. Participants are ordered from highest to lowest score.

Speech production skills were found to be variable among the group of participants. The mean percentage of expected score for the 32 participants was 87.8% (SD 14.0). This indicates that as a group the participants made approximately 12% more speech production errors than would be expected for normally hearing children.

The DEAP percentage of expected score was correlated with age at cochlear implantation ($r=-0.354$, $p=0.047$), age at identification ($r=-0.388$, $p=0.028$), age at HA ($r=-0.384$, $p=0.030$), mode of communication ($r=0.379$, $p=0.032$), family participation rating ($r=0.496$, $p=0.004$) and non-verbal IQ ($r=0.407$, $p=0.021$).

Age at cochlear implantation was not found to be significant when included in multiple regression analysis with mode of communication and non-verbal IQ. Mode of communication was not found to be significant when included in multiple regression analysis with family participation rating and non-verbal IQ. Multiple regression analysis revealed that 24.6% of the variance in DEAP percentage of expected score could be explained by family participation rating and 10% of the variance could be explained by non-verbal IQ. Total variance in DEAP percentage of expected score was explained by family participation and non-verbal IQ was 34.6%.
Figure 17: Speech production skills as measured by the DEAP for the 32 participants. Mean for the participant group was 88% and is represented by the dashed line. Typically developing children would be expected to score 100% and is represented by the solid line.

8.2.3 Phonological Processes

Participants demonstrated, on average, 13.8 different phonological processes. Participants were more likely to produce developmental processes than non-developmentl processes.

Table 10 illustrates the percentage of children exhibiting each phonological process. Phonological processes not listed were not exhibited by the participant group.
Table 10: Percentage of children exhibiting phonological processes

<table>
<thead>
<tr>
<th>Process</th>
<th>Classification</th>
<th>% of children exhibiting process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Other fronting (OFR)</td>
<td>Developmental</td>
<td>96.9</td>
</tr>
<tr>
<td>Cluster error (CE)</td>
<td>Developmental</td>
<td>84.4</td>
</tr>
<tr>
<td>Cluster reduction (CR)</td>
<td>Developmental</td>
<td>81.3</td>
</tr>
<tr>
<td>Stopping of fricatives (STF)</td>
<td>Developmental</td>
<td>71.9</td>
</tr>
<tr>
<td>Gliding of liquids (GLL)</td>
<td>Developmental</td>
<td>62.5</td>
</tr>
<tr>
<td>Voicing (VOI)</td>
<td>Non-developmental</td>
<td>62.5</td>
</tr>
<tr>
<td>Weak syllable deletion (WDE)</td>
<td>Developmental</td>
<td>59.4</td>
</tr>
<tr>
<td>Devoicing (DVO)</td>
<td>Non-developmental</td>
<td>59.4</td>
</tr>
<tr>
<td>Final consonant deletion (FDE)</td>
<td>Developmental</td>
<td>56.3</td>
</tr>
<tr>
<td>Assimilation (AS)</td>
<td>Developmental</td>
<td>50.0</td>
</tr>
<tr>
<td>Velar Fronting (VFR)</td>
<td>Developmental</td>
<td>50.0</td>
</tr>
<tr>
<td>Alveolar backing (ABA)</td>
<td>Non-developmental</td>
<td>50.0</td>
</tr>
<tr>
<td>Other backing (OBA)</td>
<td>Non-developmental</td>
<td>50.0</td>
</tr>
<tr>
<td>Palatal fronting (PFR)</td>
<td>Developmental</td>
<td>46.9</td>
</tr>
<tr>
<td>Substitution (SU)</td>
<td>Non-developmental</td>
<td>46.9</td>
</tr>
<tr>
<td>Consonant insertion (CI)</td>
<td>Non-developmental</td>
<td>43.8</td>
</tr>
<tr>
<td>Overstressed (OST)</td>
<td>Non-developmental</td>
<td>43.8</td>
</tr>
<tr>
<td>Elongation (ELO)</td>
<td>Non-developmental</td>
<td>34.4</td>
</tr>
<tr>
<td>Deaffrication (DAF)</td>
<td>Developmental</td>
<td>31.3</td>
</tr>
<tr>
<td>Frication (FRC)</td>
<td>Non-developmental</td>
<td>31.3</td>
</tr>
<tr>
<td>Syllable Deletion (SD)</td>
<td>Non-developmental</td>
<td>31.3</td>
</tr>
<tr>
<td>Cluster deletion (CD)</td>
<td>Developmental</td>
<td>28.1</td>
</tr>
<tr>
<td>Other consonant deletion (ODE)</td>
<td>Non-developmental</td>
<td>25.0</td>
</tr>
</tbody>
</table>
Each of the measures of phonological processes showed strong inter-correlations (refer Appendix 8) indicating that, for example, children who had a lower total number of phonological processes were also more likely to exhibited less developmental and non-developmental phonological processes with relative index of unintelligibility (RIU) ≥0.1. RIU is calculated by dividing the number of observed incidences of a particular phonological process by the total number of words in the sample (Crary & Comeau, 1981). RIU of 0.1 corresponds to five errors in every 50 words and allows the relative impact of a process on the child’s intelligibility to be quantified.
The number of phonological processes was also highly correlated with all measures of phonetic accuracy (refer to Appendix 8), suggesting that as phonetic accuracy improved the number of phonological processes decreased.

The number of phonological processes was correlated with age at identification ($r=0.384$, $p=0.030$), age at HA ($r=-0.391$, 0.027), mode of communication ($r=-0.399$, $p=0.024$), family participation rating ($r=-0.436$, $p=0.013$) and non-verbal IQ ($r=-0.448$, $p=0.01$). Age at identification and family participation rating were not significant when included in a multiple regression analysis together, or individually, with mode of communication and non-verbal IQ. They were both subsequently excluded from further analysis. Mode of communication and non-verbal IQ accounted for 35.3% of the variance in the number of phonological processes (mode of communication accounted for 16.0% of the variance and non-verbal IQ accounted for 19.3%).

The number of developmental phonological processes with RIU ≥0.1 was correlated with mode of communication ($r=-0.421$, $p=0.016$), family participation rating ($r=-0.378$, $p=0.033$) and non-verbal IQ ($r=-0.455$, $p=0.009$). Family participation rating was not significant when included in a multiple regression analysis with mode of communication and non-verbal IQ and was subsequently excluded from further analysis. Mode of communication and family participation rating accounted for 37.6% of the variance in developmental phonological processes with RIU ≥0.1 (mode of communication accounted for 17.7% of the variance and non-verbal IQ accounted for 19.8%).

The number of non-developmental phonological processes with RIU ≥0.1 was correlated with family participation rating ($r=-0.358$, $p=0.044$). Regression analysis revealed that parent rating accounted for 12.8% of the variance in the number of non-developmental processes with RIU ≥0.1.
8.3 Language

8.3.1 Receptive language growth

Receptive language progress over time was derived using age equivalent scores on the RI-TLS and PPVT. For the pre-operative and 12 month post-operative evaluation point the RI-TLS language comprehension subscale was used. For the two and three year post-implantation and school entry evaluation points, age equivalent scores from the PPVT were combined to derive a receptive language rate of progress.

Rate of progress for the 32 participants is seen in Figure 18. The graph shows the participant chronological age relative to their age equivalent. The dashed black line represents the progress that would typically be expected for a child with normal hearing. That is, for every year of life the child’s receptive language skills increase by 12 months (growth rate of 1.0).

All participants made positive gains in language comprehension. Mean rate of language growth for the group was 1.04 (range 0.73 to 1.52).

Mean rate of receptive language development was not correlated with any of the predictive factors included in the study. Non-verbal IQ just failed to reach statistical significance ($r=0.344$, $p=0.054$).
**Figure 18: Language comprehension growth rates as measured on the RI-TLS and PPVT for the 32 individual participants.** Each line represents an individual participant.

A regression line for each individual participant’s language growth was calculated using all available data-points. The equation for each participant’s regression line was used to calculate the intercept of this line with the x-axis in Figure 18. The purpose of this calculation was to estimate, using all available data-points for the individual child, the chronological age at which the child’s age equivalent oral language was zero, effectively representing the age at which oral language began developing.

Mean estimated age that oral language began developing (calculated as described above) for 31 participants was 0.89 years (*range* 0.03 to 2.12 yrs). Calculation could not be made for participant 24 due to insufficient data points.
Estimated age that oral language began developing was significantly correlated with age at identification ($r=0.765$, $p<0.001$), age at HA ($r=0.8$, $p<0.001$), age at cochlear implantation ($r=0.828$, $p<0.001$), and family participation rating ($r=-0.46$, $p=0.009$). It was not correlated with bilateral implantation, mode of communication, pre-op best 3FPTA, maternal education, SES, birth order or non-verbal IQ.

Regression analysis suggested that 67% of the variance in the estimated age oral language began developing was explained by age at cochlear implantation. This relationship is illustrated in Figure 19.

![Figure 19: Relationship between age at implantation and estimated age oral language began developing](image)

8.3.2 Language pre-operative and one year post-implantation

All children demonstrated both receptive and expressive language delay, as measured on the RI-TLS, pre-operatively. Mean pre-operative receptive language delay for the
groups was -0.95 years (range -2.08 to -0.45) and mean expressive language delay was -0.90 years (range -2.08 to -0.20).

By one year post-implantation, three participants no longer demonstrated a language comprehension delay and two participants no longer demonstrated an expressive language delay. Mean receptive language delay for the groups was -0.84 years (range -2.18 to 0.58) and mean expressive language delay was -0.95 years (range -2.40 to 0.33). The distribution of receptive language delay and expressive language delay at one year post-implantation is illustrated in Figure 20 and Figure 21 respectively.

Receptive and expressive language delay at one year post-implantation was significantly correlated with age at identification ($r=-0.552, p=0.001$ and $r=-0.560, p=0.001$), age at HA ($r=-0.571, p=0.001$ and $r=-0.566, p=0.001$), age at cochlear implantation ($r=-0.547, p=0.001$ and $r=-0.629, p<0.001$), family participation rating ($r=0.55, p=0.001$ and $r=0.589, p<0.001$) and non-verbal IQ ($r=0.424, p=0.016$ and $r=0.429, p=0.014$).

Multiple regression analysis suggested that age at cochlear implantation and non-verbal IQ explained 38.7% of the variance in language comprehension delay and 47.4% of the variance in expressive language delay at one year post-implantation.
Figure 20: Receptive language delay at one year post-implantation for the 32 participants

Figure 21: Expressive language delay at one year post-implantation for the 32 participants
8.3.3 Language at two years post-implantation

Results shown in Figure 22 represent the PPVT standard score for 27 participants who completed the PPVT at two years post-implantation. Five participants were not assessed due to inability to attend the assessment session. Participants ranged from 2.6 to 4.4 years of age (M 3.3 years, SD 0.53) at the time of testing.

Standard scores from 85 to 115 are considered within the normal range for children with normal hearing. Twelve (44%) of the 27 participants from the total group were performing within the normal range on the PPVT at the two year post-implantation evaluation point. Mean standard score for the group was 82, suggesting that as a group the participants were delayed compared to normal hearing peers.

PPVT standard score at two years post-implantation was correlated with age at HA ($r=-0.398$, $p=0.04$), age at cochlear implantation ($r=-0.442$, $p=0.021$), family participation rating ($r=0.517$, $p=0.006$) and non-verbal IQ ($r=0.513$, $p=0.006$).

Regression analysis suggested that 47.7% of the variance in PPVT standard score at two years post-implantation could be explained by parent participation rating and non-verbal IQ. Age at cochlear implantation was not significant when included in multiple regression analysis with non-verbal IQ.
Figure 22: Standard score as measured on the PPVT at two years post-op for 27 participants

8.3.4 Language at three years post-implantation

Results shown in Figure 23 represent the PPVT standard score for 25 participants who completed the PPVT at three years post-implantation. Seven participants were not assessed due to inability to attend the assessment session. Participants ranged from 3.6 to 5.6 years of age ($M$ 4.3 years, $SD$ 0.12) at the time of testing.

Eighteen (72%) of the 25 participants from the total group were performing within normal limits on the PPVT at the three year post-implantation evaluation point. Mean standard score for the group was 91, suggesting that as a group the participants were performing within normal limits compared to their hearing peers.

PPVT standard scores at three years post-implantation were correlated with non-verbal IQ ($r=0.481$, $p=0.015$). Regression analysis suggested that 23.2% of the
variance in PPVT standard scores at three years post-implantation could be explained by non-verbal IQ.

**Figure 23**: Standard score as measured on the PPVT at three years post-implantation for 25 participants

### 8.3.5 Language at school entry

Results shown in Figure 24 represent the PPVT standard score for 30 participants who completed the PPVT at the school entry assessment point. Two participants were not assessed due to inability to attend the assessment session. Participants ranged from 4.6 to 6.1 years of age ($M$ 5.3 years, $SD$ 0.35) at the time of testing.

Twenty (66%) of the 30 participants from the total group were performing within normal limits on the PPVT at the school entry evaluation point. This was a slight decrease (6%) compared to the 72% performing within normal limits at three years post-implantation. This small decrease is most likely the result of the increased
participant numbers included for the school entry evaluation point (25 participants assessed at three years post-implantation and 30 participants assessed at school entry). The number of participants performing within normal limits had increased by 22% compared to standard scores obtained at two years post-implantation. The change in standard score from two years post-implantation to school entry is illustrated in Figure 25. Paired T-test suggested that the increase in standard score was significant ($t=-2.63, p=0.015$).

Mean standard score for the group at school entry was 89.9, suggesting that as a group the participants were performing within normal limits compared to their hearing peers.

PPVT standard score at school entry was correlated with age at cochlear implantation ($r=-0.372, p=0.043$), mode of communication ($r=0.363, p=0.049$), family participation rating ($r=0.409, p=0.025$) and non-verbal IQ ($r=0.519, p=0.003$).

Age at cochlear implantation was not found to be significant in a multiple regression analysis with mode of communication and non-verbal IQ and was therefore removed from further analysis.

Multiple regression analysis suggested that 47.2% of the variance in PPVT standard score at school entry could be explained by family participation rating, mode of communication and non-verbal IQ. Family participation rating accounted for 25.5% of the variance, while mode of communication accounted for 11% and non-verbal IQ accounted for 10.7% of the total variance.
Figure 24: Standard score as measured on the PPVT at school entry for 30 participants

Figure 25: Standard score as measured on the PPVT at two years post-implantation and at school entry. Blue bars represent standard score obtained at
two years post-implantation and red diamonds represent standard score obtained at school entry.

Results shown in Figure 26 represent the auditory comprehension, language expression and total language standard scores on the PLS or CELF for 30 participants at the school entry assessment point. Two participants were not assessed due to their inability to attend the assessment session. Auditory comprehension standard score could not be calculated for one additional participant because insufficient subtests were completed to enable the calculation. Participants ranged from 4.8 to 6.5 years of age ($M$ 5.4 years, $SD$ 0.42) at the time of testing. A standard score between 85-115 is within the typical range for hearing children. A scores greater than 115 is above average for hearing peers.

Sixteen (55%) of the participants were performing within normal limits for auditory comprehension. Nineteen (63%) of the participants were performing within normal limits for expressive language and 15 (50%) of the participants were performing within normal limits for total language on the PLS/CELF at the school entry evaluation point.
Figure 26: Auditory comprehension, expressive language and total language standard score on PLS/CELF at school entry for 30 participants. Each dot represents an individual participant. Mean standard score for each measure is represented by the red diamond. Shaded area indicates the typical range for hearing peers (85-115).

PLS/CELF total language standard score at school entry was correlated with the number of CIs (bilateral implantation) \( r=0.415, p=0.023 \), mode of communication \( r=0.386, p=0.035 \), parent rating \( r=0.487, p=0.006 \) and non-verbal IQ \( r=0.483, p=0.007 \).

Multiple regression analysis suggested that 37.5% of the variance in PLS/CELF standard score was accounted for by the number of CIs and non-verbal IQ. Mode of communication and family participation rating were not significant in multiple regression analysis. Number of CIs accounted for 17.2% and non-verbal IQ accounted for 20.3% of the variance.
8.4 Summary of factors associated with better post-implantation outcomes

Factors contributing significantly to each of the post-implantation outcome measures are summarized in Table 11.

Table 11: Factors associated with better post-implantation outcomes

<table>
<thead>
<tr>
<th>Outcome measures</th>
<th>Independent factors</th>
<th>Environmental factors</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Speech perception</strong></td>
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<tr>
<td>Categories of Auditory Performance</td>
<td>Female gender</td>
<td>Higher family participation rating</td>
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<tr>
<td></td>
<td></td>
<td>Higher maternal education</td>
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<tr>
<td>Open-set word perception</td>
<td>Female gender</td>
<td>AO mode of communication</td>
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<tr>
<td></td>
<td></td>
<td>Higher family participation rating</td>
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<tr>
<td><strong>Speech production</strong></td>
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<tr>
<td>Phonetic accuracy</td>
<td>Higher non-verbal IQ</td>
<td>Younger age at hearing loss diagnosis</td>
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<td></td>
<td></td>
<td>Younger age at HA fitting</td>
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<td></td>
<td>Younger age at family participation rating</td>
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<tr>
<td>Percentage of expected phonemes</td>
<td>Higher non-verbal IQ</td>
<td>Younger age at hearing loss diagnosis</td>
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<td>Younger age at HA fitting</td>
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<td>Younger age at cochlear implantation</td>
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<td></td>
<td></td>
<td>AO mode of communication</td>
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<td></td>
<td></td>
<td>Higher family participation rating</td>
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<tr>
<td>Phonological processes</td>
<td>Higher non-verbal IQ</td>
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<td>Younger age at HA fitting</td>
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<td>AO mode of communication</td>
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<td>Higher family participation rating</td>
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</table>
### Outcome measures

<table>
<thead>
<tr>
<th>Language measures</th>
<th>Independent factors</th>
<th>Environmental factors</th>
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<tr>
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<td>Younger age at hearing loss diagnosis</td>
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<td>Younger age at HA fitting</td>
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<td>Younger age at cochlear implantation</td>
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<td></td>
<td>Higher family participation rating</td>
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<tr>
<td><strong>Estimated age that oral language began developing</strong></td>
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<tr>
<td><strong>Language comprehension and expression at one year post-implantation</strong></td>
<td>Higher non-verbal IQ</td>
<td>Younger age at hearing loss diagnosis</td>
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<td>Younger age at HA fitting</td>
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<td>Younger age at cochlear implantation</td>
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<td>Higher family participation rating</td>
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<tr>
<td><strong>Receptive vocabulary at two years post-implantation</strong></td>
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<td>Younger age at HA fitting</td>
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<td></td>
<td>Higher non-verbal IQ</td>
<td>Younger age at cochlear implantation</td>
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<td>Higher family participation rating</td>
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<td><strong>Receptive vocabulary at three years post-implantation</strong></td>
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<tr>
<td><strong>Receptive vocabulary at school entry</strong></td>
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<td>Younger age at cochlear implantation</td>
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<td>AO mode of communication</td>
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<td>Higher family participation rating</td>
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<tr>
<td><strong>Total language at school entry</strong></td>
<td>Higher non-verbal IQ</td>
<td>Bilateral CI</td>
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<td>AO mode of communication</td>
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<td></td>
<td></td>
<td>Higher family participation rating</td>
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8.5 Relationship between outcome measures

Correlation analysis was performed on all outcome measures described above to determine the relative associations between the measures of speech perception, speech production and language used in the present study. The correlations are detailed in Appendix 8.

It was anticipated the outcome measures would be related and multiple intercorrelations were found between speech perception, speech production and language measures at the various assessment intervals.
9 DISCUSSION

9.1 Summary of results

The first aim of this study was to describe the child and family characteristics for children who receive CIs at an early age. Hearing loss diagnosis for the group ranged from 0.04 years to 1.83 years of age. Age at HA fitting ranged from 0.13 years to 1.92 years of age, with all children receiving HAs within 6.5 months of hearing loss diagnosis. Age at implantation ranged from 0.52 years to 2.20 years of age, with the mean age at implantation for the group being 1.23 years. Seventy two percent of the group used an AO mode of communication. The participant group included a high proportion (69%) of families from SES advantaged areas and the majority of children (94%) had mothers who had completed tertiary education. Eighty four percent of the families were rated as having above average participation in their child’s intervention program. Family size ranged from one to three children, with the majority of families (69%) having two children. There was no particular trend for the position of the hearing impaired child amongst their siblings; 41% of the participants were the first born child, 31% were second born child and 28% were third born child. There was a similar ratio of boys and girls in the participant group; 17 females and 15 males. Non-verbal IQ was equivalent to that of hearing peers and was normally distributed for the participant group.

The characteristics described above were not independent from one another and were analysed as potential predictors of the speech perception, speech production and language outcomes for the participant group. The associations between the predictor variables were investigated and proved to be complex. Age at hearing loss identification, age at HA fitting and age at implantation were all significantly correlated with one another. Children who were of an earlier age at hearing loss identification received their HAs at an earlier age and subsequently received a CI at
an earlier age. Children with higher family participation ratings tended to receive an earlier cochlear implant. Families with higher SES were more likely to use an AO mode of communication with their child. Larger family size was associated with an earlier age at hearing loss diagnosis, HA fitting and implantation. Larger families also tended to use an AO mode of communication.

The second aim of this study was to provide a comprehensive description of the speech perception, speech production and language development of children who received CIs before 2.5 years of age. There was a positive progression in all participants’ auditory skills over time, with the most significant change occurring between pre-implantation and 12 months post-implantation period. By approximately five years of age all participants were able to complete an open-set word perception task. The participant group achieved a mean phoneme score of 81% and a mean word score of 56%. Speech production skills were found to be quite variable amongst the group. On average, the participant group’s phonetic accuracy, for both vowels and consonants, was significantly delayed compared to hearing peers. The participants made 12% more speech production errors compared to their hearing peers. Participants demonstrated, on average, 13.8 phonological processes that were predominantly developmental. As the participants’ phonetic accuracy improved the number of developmental and non-developmental phonological processes decreased. All participants made positive gains in their language comprehension over time. The mean rate of language growth for the group was 1.04, which is equivalent to hearing peers. The mean estimated age that oral language began developing, as derived from the regression line of each individual participant’s language growth, was 0.89 years. The number of children exhibiting a language delay reduced over time; all children exhibited a language delay prior to receiving their cochlear implant(s) whereas only 34% of the group had a language delay, as measured using the PPVT, at the time they entered primary/elementary school.
The final aim of the study was to determine the factors associated with superior speech perception, speech production and language outcomes. Pre-operative auditory skills were related to the degree of residual hearing. Children tended to acquire auditory skills more rapidly if they were female and had a higher family participation rating. Better speech perception performance at the time the child entered primary/elementary school was associated with an AO mode of communication and higher family participation rating. Higher accuracy in the speech production of phonemes was associated with an earlier age at hearing loss identification, HA fitting and implantation and higher non-verbal IQ. The children with earlier hearing loss identification, HA fitting and implantation and those using an AO mode of communication, had higher family participation rating and higher non-verbal IQ, made less speech production errors and exhibited less phonological processes.

Mean rate of language growth was not correlated with any of the predictor variables. Children who had an earlier diagnosis of hearing loss, HA fitting and implantation and higher family participation rating tended to have a younger estimated age that oral language began developing, with 67% of the variance explained by age at implantation. This was strong evidence that early implantation reduced the age that oral language began developing.

The predictive factors associated with language delay varied across assessment points. One year after implantation, children exhibited a smaller language delay if they were of an earlier age at hearing loss identification, HA fitting and implantation, had a higher family participation rating and higher non-verbal IQ. Two years after implantation, the same factors impacted on language delay, with the exception of age at hearing loss identification which was no longer significant. Three years after implantation, only higher non-verbal IQ was associated with a smaller language delay. At the time the children entered primary/elementary school two different measures of language were used; PPVT to assess receptive vocabulary and PLS to
assess total language. The factors associated with smaller language delay varied between the two measures. Children with an earlier age at implantation, those who used an AO mode of communication, had higher family participation rating and higher non-verbal IQ demonstrated a smaller delay in receptive vocabulary. Children who used bilateral implants, those who used an AO mode of communication, had a higher family participation rating and higher non-verbal IQ demonstrated a smaller delay in total language.

9.2 **Predictive factors & their interrelationships**

Three decades of research have attempted to identify the factors that affect the communication outcomes of children using cochlear implants. The extent to which a child will use the auditory information provided by a CI to develop oral speech and language skills may be affected by factors the child brings to the learning environment, characteristics of the child’s intervention program and characteristics of the family that affect the child’s learning. Characteristics of the child that have frequently been reported as impacting on outcomes for children using a cochlear implant(s) include; age at onset of hearing loss, degree of pre-implant residual hearing, age at identification of hearing loss, age at cochlear implantation, number of active electrodes available for programming in the cochlear implant, presence of a developmental delay and gender. The child’s outcome with a CI cannot be predicted by these factors alone. The following factors have also been identified as affecting outcomes; CI and speech processor technology, educational placement/mode of communication, family characteristics (e.g. maternal education and socioeconomic status) and family participation in the intervention program. Interrelationships between many of these factors make determining their relative importance challenging.
The inclusion criteria for the present study were developed in order to control or reduce the impact of many of the factors outlined above. All participants had a congenital severe-to-profound hearing loss (best 3FPTA ≥90dBHL) which eliminated the need to investigate age at onset of hearing loss and reduced the potential impact of degree of pre-implant hearing. Participants were excluded if they presented with a greater than borderline developmental delay. A similar number of males and females were recruited; 15 males compared to 17 females. All children used the latest speech processor and strategy and had 20 or more electrodes available for programming.

It was hypothesized that age at implant would have a significant and sustained effect on language delay. It would be naive, given the body of research that preceded the present study, to assume that age at implant is the only factor that impacts language delay and the other outcome measures described in this study; speech perception and speech production. The following factors were therefore included in the present study as potential predictor variables; age at identification of hearing loss, age at HA fitting, age at implantation, number of CIs (unilateral vs bilateral), mode of communication, best 3FPTA, family participation rating, maternal education, SES, birth order, family size, gender and non-verbal IQ.

Due to the inherent nature of human research, the potential predictor variables were unlikely to be independent from one another. For example, an early diagnosis of hearing loss would likely result in an earlier age at HA fitting given that one typically leads to the other. Similarly, non-verbal IQ of the child may be related to maternal education given that IQ is known to have a significant genetic component (Neisser et al., 1996). The following section describes the predictor variables for the participant group and their interrelationships. For each interrelationship, potential explanations have been provided.
Findings for SES, reported as a percentile of Relative Socioeconomic Advantage and Disadvantage, was not normally distributed for the participant group. The distribution was skewed towards higher SES, suggesting that the participant group represents a more SES advantaged group of children compared to the general population. The relationship between SES and health and developmental outcomes for children is complex. Higher SES is associated with better access to resources, including knowledge, money and beneficial social connections, that help people avoid diseases and minimize their negative consequences through a variety of mechanisms (Link & Phelan, 1995). There is no evidence to suggest that hearing loss is more prevalent amongst children with advantaged SES, in fact low SES had been associated with increased incidence of hearing loss (Egbuonu & Starfield, 1982). It is possible that families with higher SES are more inclined to seek cochlear implantation for their child as a result of better knowledge of the potential of intervention and resources to support access to relevant health services. This finding is consistent with Yoshinaga-Itano et al. (2010) who reported that the SES of many families in CI research articles are often quite high with a typical average maternal education of college education or above. Yoshinaga-Itano et al. (2010) suggested that this may contribute to an upward bias in outcomes or an indication of how family characteristics may relate to treatment choices.

The present study commenced prior to UNHS being fully implemented across the state of Victoria, the state in which all children in the participant group lived at the time of hearing loss diagnosis. As a result, identification of hearing loss for children who did not undergo UNHS required a degree of awareness from the parents to firstly identify a concern regarding hearing and secondly to seek a diagnostic hearing assessment. In a study investigating the maternal-child interactions of children with low birth weight, parents with higher SES were reported as being more sensitive to their child’s health and well-being by providing more social and cognitive stimulation (Singer et al., 2003). In a system where newborn screening is not universal, children
from higher SES may be more likely to have an early hearing loss diagnosis due to this heightened sensitivity, which in turn creates the opportunity for earlier implantation. Low SES has been identified as a barrier to early implantation (Hang et al., 2015). The age at implantation inclusion criteria for the present study was less than 2.5 years of age. This may have artificially biased the participant group to this higher SES group of well-resourced parents. This is consistent with the findings of Dettman, Dowell, and Choo (2015, accepted) who reported that earlier age at HA fitting and higher SES were associated with younger age at CI for children implanted before three years of age. Families from high SES areas may have more time and resources to help their children, more opportunities to read and understand about cochlear implantation, and may therefore have the opportunity to be more involved in the process (Geers, Brenner, et al., 2003; Hyde et al., 2011).

There are a range of communication approaches offered to families of hearing impaired children. These include approaches with visual and sign emphasis such as the exclusive use of Auslan (Australian Sign Language), and the use of Auslan within the Bilingual/Bicultural approach, and approaches with speech/audition emphasis such as Auditory/Verbal and AO approaches. Families all chose to enrol in an early intervention (EI) programme offering one or more of these approaches. Their choice would potentially be affected by a number of factors e.g. their attitude towards hearing loss, manner of delivery of the EI service or geographical proximity to the service. Seventy two percent of the participants used an AO mode of communication. A study conducted by Li, Bain, and Steinberg (2003) investigated the factors that influenced parental decision making and the choice of communication mode for children with hearing impairment children. Eighty three parents with normal hearing were surveyed regarding the extent of their child’s hearing loss, use of assistive devices, resource availability, and values, trade-offs, goals, attitudes and beliefs about hearing loss. Degree of hearing loss was found to be the most influential decision factor. The study by Li et al. (2003) also found that parental cognitive-
attitudinal factors were important in the inclination to favour an oral education approach if the parents believed that deafness can and should be corrected, or if they desired the child to be able to speak and attend a regular class in a mainstream school. This is a potential influential factor for the participant group in the present study. Parents of the participants were all normally hearing, potentially predisposing them to wanting their child to speak and assimilate in the hearing community to which the parents belong. This suggested motivation is supported by the research of Kluwin and Stewart (2000) who found that the single most important factor in the decision to have their child receive a CI was a desire on the parents’ part to have a child who might function as a hearing person. Similarly, Moog and Geers (2003) surmised “that for most parents, the primary motivation for getting a CI for their child is to help their child learn to talk, to understand speech and participate in the family social environment and the world at large” (p.124S). Schauwers et al. (2004) also reported “For hearing parents, one of the main expectations for a CI for their deaf child is the acquisition of spoken language” (p.263). In a large study conducted by Hyde, Punch, and Komesaroff (2010), 247 parents were surveyed about their decision to implant their child with hearing impairment. Seventy three percent of parents surveyed reported that their predominant reason for seeking a CI for their child was “development and use of child’s speech and hearing” and 87% indicated that they wanted their child to use speech and hearing. Families in the present study were not directly surveyed regarding their motivation to choose a particular communication mode so it can only be speculated as to the potential reasons for the high proportion of children using an AO mode of communication. Mode of communication was positively correlated with SES, suggesting that children from higher SES backgrounds were more likely to use an AO communication approach. There is some evidence that AO education is associated with better speech and language outcomes for children using CIs (Dettman, Wall, Constantinescu, & Dowell, 2013; Geers, Nicholas, et al., 2003). Given that families with advantaged SES have better access to educational
resources and information, this is a possible explanation for them choosing an AO approach.

The manner in which intervention services are delivered may also impact parental decision making. Some programs offer site-based versus home-based intervention, some offer weekly or monthly services, some services are offered by speech pathologists or teachers of the deaf. Some services offer transport assistance e.g. taxi pick up and drop off. Given more limited access to resources of lower SES families, it is hypothesized that they may be inclined to choose a service provider that offers home-based intervention to minimise travel expenses. In Victoria, at the time this study was conducted, the early intervention provider that offered home-based intervention was the service that had a greater emphasis on sign language and/or bilingual communication.

Family participation rating was used to characterize the level of family involvement in the CI intervention program. The ratings encompassed issues such as adjustment to the child’s hearing loss, session participation and effectiveness of communication with the child. The five point scale was adapted from that used by Moeller (2000), with one representing limited participation and five representing ideal participation. Family participation rating for the participant group ranged from two (below average) to five (ideal participation). No family in the present study was rated as having limited participation (rating of one). This is not surprising given that a CI is an elective surgical procedure requiring frequent medical, audiological and habilitation appointments. Families categorized as having limited participation were unlikely to present for cochlear implantation due to the commitment required. Family participating rating was not normally distributed for the participant group. Eighty four percent of the families were rated as either four (good) or five (ideal), implying that a high majority of the study participants were from highly engaged families. Similar to the suggested explanation for the higher proportion of SES advantaged families
represented in the participant group, it is likely that families that were more engaged with their child’s intervention sought early implantation (before 2.5 years of age). This was further supported by the significant negative correlation between age at implantation and family participation found in the present study.

Parental factors have been identified as being a barrier to early implantation. A recent study by Armstrong et al. (2013), describing the barriers to early implantation, suggested that the most commonly identified barrier was related to parental factors associated with appointment attendance. Armstrong et al. (2013) highlighted delayed or missed appointments, either because of difficulty navigating the system, poor compliance with appointments, or reluctance to pursue further evaluations or surgery as key barriers to early implantation. It could be postulated that SES and family participation are related given that lower SES is linked with lower education, lack of access to educational resources, less social supports and more difficulty attending appointments in terms of time/support/access to transportation (Armstrong et al., 2013). The present study found no correlation between SES and family participation rating amongst the participant group.

Maternal education ranged from completion of secondary education to post-graduate education for the participant group. Ninety four percent of mothers were educated beyond secondary school, 67% had completed a bachelor degree and 31% had completed a post-graduate qualification. A recent review of educational attainment in the world found that 17.9% of the population in advanced countries (including Australia) had a tertiary education (Barro & Lee, 2013). The mothers of the participant group represent a more highly educated group of individuals compared to the general population in Australia. Higher maternal education is associated with attitudes towards education, knowledge and beliefs about child development (Dollaghan et al., 1999). Mothers with higher education may be more inclined to seek cochlear implantation for their child as a result of better knowledge of the potential
intervention, more resources to help their children, more opportunities to read and understand about cochlear implantation and may be more involved in the process. These mechanisms are similar to those that may motivate a family with higher SES to seek cochlear implantation before 2.5 years of age. It could be anticipated that high maternal education and high SES are associated given that both result in improved access to resources; personal and material. Education has been linked to positive health outcomes (Winkleby, Jatulis, Frank, & Fortmann, 1992). The most plausible explanation for this link is that education may protect against disease by influencing lifestyle behavioural, problem solving abilities and values (Liberatos, Link, & Kelsey, 1988). It has been suggested that education may facilitate the acquisition of positive social, psychological and economic skills and assets, and may provide insulation from adverse influences (Winkleby, Fortmann, & Barrett, 1990). The link between education and SES has received significant attention in the field of economics with most concluding that the relationship is multifaceted and ambiguous (Gregorio & Lee, 2002). Maternal education was not correlated with SES status in the present study. Maternal education has previously been reported as a predictor of family participation, with family participation increasing with higher educational attainment of the primary caregiver (Sarant et al., 2009). In the present study, maternal education and family participation rating had a weak negative correlation, which just failed to reach significance. A possible explanation for this contrasting finding was the lack of diversity in maternal education and family participation in the present study’s comparatively small participant group. Only two mothers had not completed an educational qualification beyond secondary education and both were rated as having ideal family participation. This suggested that a lower level of maternal education does not preclude a family from being highly engaged with their hearing impaired child’s intervention in the participant group.

In the present study, family size ranged from one to three children (including the participant). Larger family size was associated with an early age at hearing loss
identification, HA fitting, and age at implantation, AO communication approach and higher family participation rating. There is little precedence in the literature for the positive effects of larger family size and the above factors. Fifty nine percent of the participants were the second or third born child. It is proposed that having an older hearing sibling or siblings provides parents with a model of hearing children’s behaviours. It is possible that this model or comparison with an older sibling with normal hearing enabled parents to detect a difference in their child with hearing impairment’s early behaviour that may alert them to a concern about hearing, for which they subsequently received a diagnosis.

Hearing loss diagnosis must precede HA fitting and cochlear implantation so it is not unexpected that these two factors were also correlated with family size. Kluwin and Stewart (2000) suggested that hearing families may be inclined to choose an AO education approach because of their desire “to have a child who might function as a hearing person” (p.29). This desire may be heightened in the presence of multiple siblings, with normal hearing, with whom the parents hope the child with hearing impairment will assimilate. The positive effect of family size on family participation rating is of note. Moog and Geers (2003) suggested that the number of children in the family may reflect the amount of time or other resources available to parents to focus on their child’s hearing and engage in their child’s intervention. In the participant group it appeared that the opposite may have been true. It is possible that the presence of a sibling or siblings with normal hearing, particularly if older, provides the child with a hearing loss with additional language models and increased opportunities for communication.

Non-verbal IQ for the participant group was normally distributed, with the mean performance scale score being 101.5 and the range being 76-137. It has been suggested that IQ results from a combination of genetic and environmental factors. Various studies on the hearing population have found the heritability of IQ to be
between 0.7 and 0.8 in adults and 0.45 in childhood (Bouchard, Lykken, McGue, Segal, & Tellegen, 1990; Neisser et al., 1996; Plomin, Pedersen, Lichtenstein, & McClearn, 1994). Environmental factors, biological and social, are also important for IQ, however the underlying mechanisms are not well understood. Environment and its interaction with genes account for the remaining approximate 50% of IQ in hearing children. Resources of the home and parents’ use of language are correlated with hearing children's IQ, but such correlations may be influenced by genetic as well as (or instead of) environmental factors. There is also a likely influence from peers and other experiences outside the home (Neisser et al., 1996). Numerous studies have documented that low SES and low parental education are associated with lower IQ later in childhood amongst the hearing population (Bradley & Corwyn, 2002). Non-verbal IQ was not correlated with any of the other predictor variables, including SES and maternal education, in the present study. The absence of an association in the present study may have resulted from the lack of diversity in SES and maternal education for the participant group or alternately the relationship between these factors may be different in the hearing impaired population.

Earlier age at hearing loss identification was associated with earlier age at HA fitting for the study participants. This is not an unexpected finding given that hearing loss diagnosis is a precursor to HA fitting. Seventy five percent of the participant group received their HAs within five weeks of hearing loss diagnosis. The two children (participants 10 and 18) with the longest duration between hearing loss diagnosis and HA fitting had findings consistent with auditory neuropathy spectrum disorder (ANSD). The protocol for fitting HAs to children with ANSD is somewhat different to that of children with SNHL. Some have argued that HAs are of no benefit to this population and should not be fitted at all (Berlin, 1999; Doyle, Sininger, & Starr, 1998). While others have reported that approximately 50% of children with ANSD can benefit from conventional amplification (Rance, Cone-Wesson, Wunderlich, & Dowell, 2002). In Australia, children with findings consistent with ANSD are fitted with HAs
once behavioural hearing levels can be estimated. In cases of ANSD the behavioural hearing levels cannot be predicted from objective test results in the same way they can be for children with SNHL (Rance et al., 1999). Therefore HA fitting is often delayed until behavioural testing can be completed and this is the likely explanation for the long duration between hearing loss diagnosis and HA fitting of participants 10 and 18. The benefit of using HAs will depend on the degree of hearing loss for children with SNHL. When the hearing loss is in the profound range, HA fitting and trial is no longer considered a prerequisite to CI assessment and a prompt referral for CI assessment is encouraged (Hang et al., 2015; Leigh et al., 2011). It was hypothesized that earlier age at hearing loss diagnosis would result in earlier cochlear implantation for the participant group. Earlier age at identification of hearing loss creates the opportunity to provide a child with an early implant and this was found in the present study; those children diagnosed earlier also received the CI earlier. This trend of early diagnosis leading to earlier implantation has recently been described. Young, Reilly, and Burke (2011) reported a significant decline in the age of implantation for a large cohort of children (n=391) diagnosed after the implementation of UNHS compared to before implementation in the state of Illinois, USA. The earlier age of implantation was attributed to the earlier definitive diagnosis of hearing loss for the children who underwent UNHS, permitting time for the medical and audiological evaluations needed to confirm CI candidacy. Dettman et al. (2015, accepted) reported a similar finding, although used age at HA fitting rather than age at diagnosis of hearing loss as the reference point. Dettman et al. (2015, accepted) found a significant reduction in age at implantation from 1985, when paediatric implantation was first undertaken, to 2014 (n=802). A similar trend was noted for age at HA fitting and earlier age at HA fitting was significantly associated with earlier cochlear implantation \( (p<0.05) \). Collectively, the studies conducted by Young et al. (2011), Dettman et al. (2015, accepted) and the present study support the hypothesis that early diagnosis of hearing loss is precursory to provision of an early CIs.
Higher family participation rating was associated with earlier age at implantation. There are multiple ways to interpret the underlying mechanism for this relationship. Children were more likely to receive an early CI if their parents were better adjusted to their hearing loss, more engaged in habilitation sessions and more effective at communicating with their child. The reverse statement may be equally valid; families whose child received an earlier CI were more engaged in their child’s intervention program. There is a link between parental high expectation of communication outcomes and positive communication outcomes for children using CIs (Hyde et al., 2011). Hyde et al. (2011) suggested that parents who were generally optimistic have high motivation to dedicate the amount of time, work and effort needed for optimal outcomes from cochlear implantation in children. High expectations of their children’s achievements contributed to parental efforts and to children’s achievement. There was also a link between parent’s expectations and their drive to ensure that their children did well with the CI (Hyde et al., 2010). Given the emerging evidence of the benefits of early implantation it was likely that the families included in the present study would have been given higher expectations for oral speech and language outcomes compared to a decade ago. It appears that this might be a positively reinforcing cycle of behaviour and events; improved language outcomes are observed for children with an earlier age at implantation, early implantation leads to higher expectations for outcome, and high expectations lead to higher parental involvement, higher parental involvement leads to better language outcomes.

### 9.3 Speech Perception

Speech perception is a fundamental skill that is essential for the development of oral speech and language. It is also the skill most frequently reported when describing the benefits of CIs for both adults and children. The subsequent section details the speech perception skills of the 32 study participants over time. Factors contributing to speech
perception performance will be discussed and compared to the existing literature on the topic.

There was progression in all participants’ auditory skills over time. Pre-operatively the majority of children showed no awareness of sound. This is consistent with all children having severe-to-profound hearing loss (best 3FPTA ≥90 dBHL) and gaining minimal benefit from conventional HAs. Three children demonstrated awareness of environmental sounds pre-operatively (CAP score of one). Pre-operatively, the CAP score was significantly correlated with pre-operative residual hearing. Those children with higher pre-operative CAP scores were more likely to be those participants with more pre-operative residual hearing.

The most significant gains in the CAP score occurred in the first 12 months after implantation. All children progressed at least five categories on the CAP scale during this time period. Mean CAP score 12 months after implantation was five (‘understands common phrases without lip-reading’). There was a significant positive correlation between pre-operative CAP scores and the CAP scores at 12 months post-implantation, suggesting that those children with better pre-operative auditory skills tended to have more advanced auditory skills 12 months post-implantation. The CAP score at 12 months was positively correlated with family participation rating and negatively correlated with maternal education. Female participants also tended to have a higher CAP score 12 months post-implantation. Correlation between family participation rating and maternal education just failed to reach statistical significance ($r=-0.329, p=0.066$). Despite the lack of significant correlation, the trend suggested that more highly educated mothers were less ideally involved in their child’s intervention. The interaction between these two factors for the participant group, in addition to the finding that families of female participants also tended to be more ideally involved in their child’s intervention, makes determining a causal relationship problematic. The lack of diversity in the mother’s education observed for the
participant group is likely to have confounded this finding. Examination of the individual data points for 12 months post-operative CAP scores revealed that several of the children with mothers who had completed post-graduate education obtained CAP scores of six (higher than the average CAP score for this assessment point). It seems most plausible that family participation accounts for some of the variance in the CAP scores 12 months after implantation and that other unaccounted for/unmeasured factors explain the majority of the difference observed between participants.

The median CAP score 24 months after implantation was six ('understands conversation without lip-reading with a familiar talker'). The CAP score at 24 months was significantly correlated with the CAP score at 12 months and no longer correlated with pre-operative CAP score, which suggested that those who had superior CAP score at 12 months also had superior CAP scores at 24 months post-implantation and that pre-operative auditory skills were no longer an influential factor. The CAP score 24 months post-implantation was significantly correlated with family participation rating and gender. Family participation rating and gender could not be combined in a multiple regression analysis due to their correlation with one another. Regression analysis suggested that 18.36% of the variance in the CAP score was explained by family participation. This finding suggested that those children with higher family participation achieved higher CAP scores at 24 months. It should be highlighted though that over 80% of the variance remained unexplained.

The median CAP score 36 months after implantation was seven ('can use the telephone with a familiar talker'). Seven is the maximum score achievable on the CAP. Only four children had not achieved a CAP score of seven by 36 months which suggested a likely ceiling effect for this assessment point. The CAP score at 36 months post-implantation was correlated with CAP at 24 months and not correlated with the CAP score pre-operatively or 12 months post-implantation. This again
suggested that those children with superior auditory skills at 24 months post-implantation also had superior skills at 36 months post-implantation. The CAP score at 36 months was significantly correlated with family participation and gender. Family participation rating and gender could not be combined in a multiple regression analysis due to their correlation with one another. Regression analysis suggested that 21.8% of the variance in the CAP at 36 months post-implantation was explained by family participation.

The CAP score was not correlated with chronological age at any of the assessment points. Three children had achieved phone use (with a familiar talker) by 24 months post-implantation. These three children ranged from 2.9 to 3.6 years of age at the time they acquired this skill. Phone use (with a familiar talker) has been reported as being achieved, on average, by 30 months of age in the normal hearing population (Govaerts et al., 2002). The child, participant 28, who achieved this skill at the youngest chronological age (2.7 years) received their CI at 1.7 years of age, had a mother with post-graduate education, was from a high SES area, had a family rated as ideally involved in their child’s intervention and had above average non-verbal IQ (107). The majority of the children achieved this skill between 3.5 and 5.2 years of age. It appears that most children who receive a CI before 2.5 years of age, with no additional disability, will develop the auditory skills necessary to use the phone within three years of receiving their cochlear implant.

Family participation rating was the only factor that appeared to have a consistent and sustained relationship with the CAP score across assessment intervals. This suggested that parental input had the ability to influence early auditory skills in a significant way. The parents rated as having higher family participation were potentially more actively involved and engaged in more activities that provided auditory experiences for their child during this critical time, potentially contributing to faster progress in auditory development.
The CAP achievements of the participants in the present study are comparable to a recent study by Colletti et al. (2011). Colletti et al. (2011) reported that 100% of children implanted before three years of age reached a CAP score of seven by 3.5 years post-implantation (n=73). Four children in the present study did not achieve a CAP score of seven by three years post-implantation. It is possible that with an additional six months device experience that these four children may have achieved a CAP of seven. Not all children had achieved a CAP score of seven by 36 months post-implantation in the Colletti et al. (2011) study. Colletti et al. (2011) did find however, that the children who received their CI between 24 and 35 months took longer to achieve a CAP score of seven compared to those who received their CI before 24 months. In the present study there was no effect of age at implantation on the CAP score at any time point. This is possibly the result of the larger proportion of children who received their CI between 24 and 35 months in the Colletti et al. (2011) group; 43% compared to 13% in the present study.

Govaerts et al. (2002) provided normative data of the CAP scores for 113 children with normal hearing; at 12, 18, 24, and 30 months of age the infants reached a mean CAP score of two, five, six, and seven, respectively. The children in the present study reached CAP scores at a comparatively older age compared to their peers with normal hearing. If hearing age, chronological age minus age at implantation, is taken into consideration, the participant group are achieving superior scores at 12 months compared to peers with normal hearing and equivalent scores at 24 and 36 months. This suggested that the difference in scores achieved by the participant group compared to children with normal hearing is likely due to the period of auditory deprivation they experienced prior to receiving their cochlear implant.

The CAP provides a useful tool for quantifying the auditory progress of very young children prior to them reaching a chronological and developmental age appropriate to complete formal speech perception testing. The CAP, however, is limited in its
sensitivity, as illustrated by the fact there is very little variability in CAP score for the group at any particular evaluation interval.

Around the time the 32 participants entered primary/elementary school, all children had reached a chronological age and developmental stage appropriate to administer formal speech perception testing; open-set monosyllabic words presented audition alone. Mean open-set word score when scored for whole words correct was 56% and when scored for phonemes correct was 81%. Speech perception score was not correlated with age at implant. Phoneme score was significantly correlated with family participation rating and mode of communication. Children who had higher family participation ratings and those who used an AO communication mode tended to have higher phoneme scores. Multiple regression analysis suggested that 38.81% of the variance in phoneme score could be explained by family participation rating.

Word score was significantly correlated with family participation rating and non-verbal IQ. Children who had higher family participating ratings and those with higher non-verbal IQ tended to have higher word scores. Multiple regression analysis suggested that 37.5% of the variance in word score could be explained by family participation.

The absence of a significant association between age at implantation and speech perception score for the participant group suggested that all children implanted before 2.5 years of age had the potential to achieve significant open-set speech perception. The child’s ability to achieve these impressive scores appeared to be related to their family participation rating rather than the age they received their cochlear implant. This finding is consistent with the relationship found between family participation rating and CAP score, and suggested that family participation had a sustained effect on auditory skills over time. Potentially those parents rated more highly on family participation were those who provided their child with varied and relevant auditory experiences which resulted in superior speech perception performance.
The significant finding for mode of communication and phoneme score is one that can be debated. It could be argued that use of TC resulted in poorer speech perception performance. Equally it could be argued that children with poorer speech perception performance are more likely to be placed in education settings with an emphasis on a visual mode of communication. In the present study the later explanation is unlikely because choice of communication mode was made before the child’s speech perception potential using a CI was known. There were only two participants, participants 14 and 16, who changed communication mode during the duration of the present study. In both cases the child transitioned from Category 3 (TC with a speech emphasis and some periods each day where only speech was used) to Category 2 (TC with an equal emphasis on speech and sign). Participant 14 scored below the group mean for open-set speech perception testing (word score 30% and phoneme score 59%) whereas participant 16 scored just above the group mean (word score 62% and phonemes 85%).

There was a significant correlation between open-set word score and non-verbal IQ. This interaction is multifaceted given that non-verbal IQ and speech perception score were both significantly correlated with the two language measures (PPVT & PLS) administered at school entry. Open-set speech perception performance is a measure of auditory skills. It is unlikely however, that the result on a speech perception task is truly independent of language skills if the words used are real words. Language skills play a more significant role in the perception of whole words in comparison to individual phonemes. This explains the association between non-verbal IQ and word score in the absence of an association between non-verbal IQ and phoneme score for the present study.

A monosyllabic word test requires that a child repeat the word as they perceive it, without necessarily understanding the meaning of the word. Linguistic competence has been found to have a significant effect on speech perception scores for hearing
impaired children (Blamey & Sarant, 2002; Cowan et al., 1997; Paatsch, Blamey, Sarant, Martin, & Bow, 2004). A child’s speech production skills may also impact on their ability to repeat a perceived word. Paatsch et al. (2004) found that a child’s speech production skills influenced their measured phoneme scores on an open-set word test more than did their lexical knowledge. They also found that whole word scores were affected by both the child’s level of lexical knowledge and speech production abilities. This is consistent with the findings in the present study whereby speech perception scores were correlated with language and speech production skills at school entry.

The speech perception scores for the participant group were higher than those previously reported by Geers, Brenner, et al. (2003) and Dowell, Dettman, Blamey, et al. (2002) for children with similar duration of CI experience. The Geers, Brenner, et al. (2003) and Dowell, Dettman, Blamey, et al. (2002) studies represent two large studies (n=181 and n=102 respectively) reporting open-set speech perception scores for children using cochlear implants. The major difference between the present study and that of Geers, Brenner, et al. (2003) and Dowell, Dettman, Blamey, et al. (2002) is the age at implant of the participants. The mean age at implant in the Geers, Brenner, et al. (2003) study was 3.42 years and Dowell, Dettman, Blamey, et al. (2002) study was 5.9 years compared with 1.23 years for the present study. The trend for children who receive a CI at a younger age achieving superior speech perception skills compared to their counterparts who receive a CI at a comparatively older age has recently been described by Dettman et al. (2016). Dettman et al. (2016) reported on the speech perception skills for 125 children who received a CI before five years of age and were assessed around the time they entered primary/elementary school. The children who received their CI before 24 months of age achieved superior speech perception scores compared to those who received a CI after 24 months of age. The mean open-set phoneme score for the children implanted before 24 months of age was 72% and is consistent with the present study.
Earlier age at implantation is beneficial for long term speech perception performance and several studies have validated this statement, however, a recent meta-analysis concluded that there was limited evidence of improved auditory performance for children implanted before 12 months (Vlastarakos et al., 2010). A number of studies reporting speech perception performance and/or auditory skill development for children who receive a CI before 12 months of age have found modest or no long-term advantage of implanting before 12 months compared to implanting at older ages (Colletti et al., 2011; Colletti et al., 2005; Lesinski-Schiedat et al., 2004; Schauwers et al., 2004). Lesinski-Schiedat et al. (2004) reported that children implanted by 12 months of age showed greater improvement in open-set speech understanding compared to children implanted between one and two years of age, at two years post-implantation. There were however, only seven children in the younger group so conclusions drawn from this study are limited. In contrast, two more recent studies have described equivalent performance on speech perception testing for children implanted by 12 months of age and those implanted between one and two years of age (Colletti et al., 2011; Holt & Svirsky, 2008).

The speech perception findings of the present study were consistent with those of Holt and Svirsky (2008) and Colletti et al. (2011) who both found no speech perception advantage for children receiving their CI by 12 months of age over those who received their implant between 12 and 24 months of age by two years post-implantation. This is also supported by the recent findings of Dettman et al. (2016) who reported no difference in speech perception performance for children who received a CI before 12 month of age compared to those who received a CI between 12 and 24 months through to late primary/secondary school (average age at testing was 9.1-9.4 years). Collectively these studies support the presence of a sensitive period for the development of auditory skills which extends well into the second year of life. Although it may be possible for children who received their CI up to 2.5 years
of age to develop good speech perception, the child’s next challenge is to use these perceptual skills to develop speech production and spoken language skills.

### 9.4 Speech production

Describing speech perception benefits for children using CIs is important as it is a direct measure of auditory skill and the CI is fundamentally a “hearing” device. Outcomes however, for children using CIs often focus on language skills given that the goal for most families is that their child becomes a successful oral communicator. Speech production skills, as assessed on a standardized measure of articulation, have been found to predict speech intelligibility (Ertmer, 2010). Poor speech intelligibility can result in significant communication breakdown (Tye-Murray et al., 1995). Speech productions skills therefore play a crucial role in overall oral communication, the importance of which should not be overlooked.

The acquisition of speech production skills consists of two key components; the phonetic level, which relates to the physical production or ‘articulation’ of speech sounds and the phonological level, which relates to the knowledge of, and the ability to produce, patterns of sounds in accordance with the rules of the native language. Both components are thought to be equally important. The subsequent section will discuss the speech production skills of the 32 children using CIs and the factors that influenced their performance.

Speech production skills of the participants were assessed at a single assessment interval; around the time the children entered primary/elementary school and at a mean age of 5.6 years. Typically developing children with normal hearing are not expected to have developed a full phonetic repertoire until between four and seven years of age so it was expected that the participant group would exhibit some speech production errors and phonological processes.
As a group the participants were demonstrating a delay in phonetic accuracy compared to peers with normal hearing. Phonetic accuracy was slightly better for vowels compared to consonants, although there was no statistically significant difference in performance. Sixty two percent of the group performed below the typical range for age matched peers for vowel production and 66% of the group were below the typical range for consonant production. Fifty three percent of the group was below the typical range for phoneme production. These findings are consistent with those of Serry and Blamey (1999) and Blamey, Barry, and Jacq (2001) who conducted two longitudinal studies into the phonetic development of nine implanted children for four and six years post-implantation respectively. In comparison to children with normal hearing, these studies reported that children using CIs demonstrated a similar pattern of phoneme acquisition, although the rate of development was often slower. Blamey, Barry, and Jacq (2001) also reported that speech development appeared to plateau after approximately six years of CI experience without all sounds having been acquired. This suggested that the speech acquisition process was still incomplete for children using a CI at an age when children with normal hearing have mastered speech production. Methodological differences prevent direct comparison between the participants in the Serry and Blamey (1999) and Blamey, Barry, and Jacq (2001) studies and the present study. Whereas the present study used a standardized articulation assessment, Serry and Blamey (1999) and Blamey, Barry, and Jacq (2001) used transcribed spontaneous speech samples to quantify speech production skills and reported on phoneme acquisition using two different criteria; targetless (produced a phonetically recognizable sound spontaneously) and targeted (produced the phoneme correctly at least 50% of the time in a meaningful word). A marked difference also existed between the age at implantation of the participants in the present study and that of Serry and Blamey (1999) and Blamey, Barry, and Jacq (2001). The nine children in the Serry and Blamey (1999) and Blamey, Barry, and Jacq (2001) studies received their CIs at an average age of 3.75 years (range 2.5 to 5.17 yrs) compared to the average age of implant of 1.25 years (range 0.52 to 2.20 yrs).
yrs) in the present study. Blamey, Barry, and Jacq (2001) hypothesized that the plateau in performance that was observed after six years of CI experience was due to decreasing neural plasticity, as the group’s average age at the conclusion of the study was 9.75 years. The children in the present study were on average 5.6 years at the time they were assessed with an average CI experience of 4.3 years (range 2.9 to 7.5 yrs). It is therefore possible that they have not reached their speech production potential and will continue to improve their accuracy as they mature. More long term follow up is required in order to investigate this.

A number of studies have described the speech production skills of children using CIs as being delayed compared to chronologically age matched peers on a standardized test of articulation; the Goldman-Fristoe Test of Articulation (GFTA). Chin and Kaiser (2000) reported that only two out of 10 participants performed above the 10th percentile relative to their chronological age using the first edition of the GFTA (GFTA-1). Buhler et al. (2007) reported that only two of their five participants obtained standard scores that fell within 1.5 standard deviations of the mean using the second edition of the GFTA (GFTA-2). More recently Flipsen Jr (2011) reported five of the 15 participants (33%) achieved standard scores on the GFTA-2 that fell within 1.5 standard deviations of their chronological age. The present study therefore reports higher levels of performance, with 47% of children performing within the normal range for their chronological age, compared to previous reports. Once again, mean age at implantation for the participant group was notably younger compared to these previous reports which suggested that as the international trend shifts towards implanting children at progressively younger ages reports of improved performance in speech production may emerge.

Production of vowels was correlated with age at identification, age at HA, age at cochlear implantation, non-verbal IQ, mode of communication, family participation rating and best 3FPTA. Age at cochlear implantation and family participation were not
found to be significant when included in separate multiple regression analyses with mode of communication, best 3FPTA and non-verbal IQ. Just over forty six percent (46.39%) of the variance in vowel score was explained by mode of communication (15.2%), best 3FPTA (11.1%) and non-verbal IQ (20.1%).

Production of consonants was correlated with age at identification, age at HA, age at cochlear implantation and non-verbal IQ. Age at cochlear implantation was not significant in multiple regression analysis. Non-verbal IQ alone explained 24.31% of the variance in consonant score.

Production of overall phonemes was correlated with age at identification, age at HA, age at cochlear implantation, non-verbal IQ and family participation rating. Age at cochlear implantation and family participation rating were not significant when included in separate multiple regression analysis with non-verbal IQ. Non-verbal IQ alone explained 25.82% of the variance in phoneme score.

Across all three measures of phonetic accuracy, non-verbal IQ was the most significant and consistent predictor of performance, explaining over 20% of the variance on all three measures. Although initially associated with superior phonetic accuracy, age at implantation and family participation rating appeared to have minimal impact when non-verbal IQ, mode of communication (for vowel accuracy) and best 3FPTA were taken into consideration.

Several factors have been identified in the literature as playing a role in the variability of speech production skills for children using cochlear implants. Early reports suggested that mode of communication played a key role (Connor et al., 2000; Geers & Moog, 1992; Geers et al., 2000). It remains unclear, however, precisely how mode of communication enhances or detracts from the development of spoken language skills. Most reports to date have included children implanted older or were completed
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with children using HAs and may not reflect present day influences for early implanted children. There are a number of other potential variables that influence oral communication including factors associated with the child, family, device characteristics, school settings and patterns of intervention. Tobey et al. (2003) attempted to describe these variables by investigating the speech production skills of 181 children using cochlear implants. Mean age at implantation for the cohort was 3.4 years (range 1.7 to 5.3 years). Twenty two percent of the variance in speech production skills was explained by performance IQ, gender, family size and SES. Children with higher performance IQ, who came from smaller families and were from higher SES families, demonstrated higher speech production scores. Speech production scores were also higher for children in mainstream settings who primarily communicated using AO modes.

A follow up study by Tobey, Geers, Sundararajan, and Shin (2011) evaluated the speech production of a subset of 110 adolescents of the original 181 children in Tobey et al. (2003) and further emphasized the influence of mode of communication on speech production skills. Their study also demonstrated that speech production could improve into adolescence. A finding which differed to that of Blamey, Barry, and Jacq (2001) who suggested a plateau in skills after six years device use.

Pre-operative level of residual hearing has also been demonstrated to influence speech intelligibility and consonant accuracy of children using cochlear implants (Sundararajan, 2015; Svirsky, Chin, & Jester, 2007). In a longitudinal study of 128 children using cochlear implants, Sundararajan (2015) reported that children with higher levels of preoperative residual hearing exhibited higher consonant accuracy scores at 4 years of device experience.

In all the studies described above, the children on average demonstrated delayed speech production compared to peers with normal hearing irrespective of the age
they were evaluated. One exception to this is the findings of Schorr, Roth, and Fox (2008) who reported that the articulation abilities of children using CIs and children with normal hearing were not significantly different. The inclusion criteria of the Schorr et al. (2008) study may provide insight into this unique finding. The participants were required to have language proficiency of five years of age or better and were exclusively exposed to oral communication. Given the link between language and speech production skills this will have potentially skewed the CI group of children in their study to a high performing group and therefore these findings cannot be generalized to the broader group of children using CIs. Another factor that limits the generalizability of these previous studies is the relatively late/older age at implantation of the majority of the participants. Many of the children described have received a CI well beyond the critical period for speech production.

The speech production skills of the children in the present study were further described by calculating the individual child’s percentage of the expected score on the standardized articulation test. For each participant, the percentage of expected score was calculated by dividing the child’s percentage of phonemes correct by the expected percentage of phonemes correct (50th percentile) for typically developing child of equivalent age. The mean percentage of expected score for the group was 87.8%, suggesting that as a group the children made just over 12% more speech production errors than would be expected for children with normal hearing of equivalent age.

Percentage of expected score was correlated with age at cochlear implantation, age at identification and age at HA, mode of communication, family participation rating and non-verbal IQ. Age at cochlear implantation was not found to be significant when included in multiple regression analysis with mode of communication and non-verbal IQ. Mode of communication was not found to be significant when included in multiple regression analysis with family participation rating and non-verbal IQ.
percent of the variance in percentage of expected score could be explained by family participation rating and ten percent of the variance could be explained by non-verbal IQ. Total variance explained by family participation and non-verbal IQ was 34.6%. This is consistent with the findings of Leigh et al. (2013) who also found that speech production skills were negatively correlated with age at implantation and positively correlated with mode of communication and suggested that better speech production performance was associated with earlier age at implant and a mode of communication with a greater AO emphasis.

Consistent with the finding for phonetic accuracy for the participant group, the percentage of expected score suggested the participant group was delayed compared to their hearing peers. It can be concluded that having a CI before 2.5 years of age is not young enough to ensure age appropriate speech production skills to develop. The present study was not able to identify a critical period for age appropriate speech production to develop. Alternately, perhaps the signal provided by the CI may not be of sufficient quality to allow timely development of speech production skills.

Research investigating the speech production skills of children who received their CI in the first year of life has provided some insight into the critical period for this communication competency. Speech production, measured as the onset of babbling and babbling spurt, has been described as following a similar pattern of development to children with normally hearing if the children with hearing impairment receive CIs in the first year of life (Colletti et al., 2005; Schauwers et al., 2004). In the studies by Schauwers et al. (2004) and Colletti et al. (2005), post-operative follow up was limited to one and two years respectively. It is therefore unclear whether these encouraging findings for babbling onset and spurt develop into age appropriate phonological skills when the children reach school age. Leigh et al. (2013) evaluated the speech production skills of children who received a CI before two years of age around the time the child entered primary/elementary school on a standardized
articulation test, using the same methodology used in the present study. The children who received their implant by 12 months of age achieved a greater percentage of expected phonemes correct compared to children who received their CI between 13 and 24 months. The difference between groups just reached significance on a directional T-test ($p=0.033$) however, both groups performed significantly poorer than their hearing peers. Dettman et al. (2016) reported a similar advantage for 23 children who received a CI between six and 12 months of age compared to 53 children who received their CI between 13 and 42 months. The superior performance of the youngest group (CI between 6-12 months) in Leigh et al. (2013) and Dettman et al. (2016) is consistent with the findings of Colletti et al. (2005) and Schauwers et al. (2004) suggesting that an early age at implantation, specifically before 12 months of age, leads to better speech production skills. In contrast, Holt and Svirsky (2008) and Habib, Waltzman, Tajudeen, and Svirsky (2010) found that children implanted before age 12 months and those implanted between 12-24 months showed no difference in their speech production development. A consistent finding across most studies was that speech production was delayed for children using CIs compared to normally hearing peers. This suggested that more directive remediation of speech production skills may be required for all children using cochlear implants, even when implanted at a very early age, to ensure their long-term speech production skills and intelligibility is not adversely affected as the child matures. It may also be possible that the children in the present study will catch up to their normally hearing peers given that speech production skills can progress into the seventh and eighth year of life (Kilminster & Laird, 1978). Further investigation, including more long term follow up, into the area of speech production is clearly warranted. Future research will aim to clarify the critical period during which children should receive a CI in order to facilitate speech production outcomes that are equivalent to those of children with normal hearing.
Consistent with the existing literature on hearing impaired children using HAs and children using cochlear implants, both developmental and non-developmental phonological processes were observed in the participant’s speech, however, developmental processes were more prevalent. Nine phonological processes were present for more than 50% of the participants. Of these nine processes, seven were developmental processes that would be produced by children with normal hearing and two were non-developmental. The most common developmental processes observed in the present study included: other fronting (distinct from palatal fronting), cluster error, cluster reduction, stopping, gliding of liquids and final consonant deletion. The most common non-developmental processes observed included: voicing, devoicing and weak syllable deletion.

Flipsen and Parker (2008) reviewed 11 previous studies describing the phonological patterns of children with moderate to profound hearing loss using HAs. The authors noted that the most commonly observed developmental pattern was final consonant deletion and the most commonly observed non-developmental pattern was initial consonant deletion, each observed in 10 out of the 11 studies reviewed. Final consonant deletion was the ninth most prevalent developmental process observed in the present study and was observed in 56.3% of the participants. Initial consonant deletion was not commonly observed in the participant group and occurred for only 15.6% of the group. This contrast in findings for phonological processes is likely a reflection of the different technology used by the participants and different methodology used to code the phonological processes. Speech production skills for children with hearing loss are not only influenced by natural developmental constraints but also by the amount and quality of acoustic information made accessible to them through hearing technology. Those children using HAs, particularly those with more significant losses are less likely to have access to all the sounds of speech through their hearing technology. As a result, more speech production errors are likely to occur because they are unable to hear the “correct” speech production
model. In contrast, children using CIs are anticipated to have full access to all the sounds of speech. The individual child’s speech production skills are more likely to be dependent on their capacity to interpret the degraded signal provided by the CI and translate it into speech recognition which provides them with access to the “correct” speech production model.

Developmental processes are usually described as those which occur regularly in the speech of younger, typically developing children. Established reference data suggested that certain processes are resolved earlier than others (Grunwell, 1987; Roberts et al., 1990). For example, Grunwell (1987) indicated that final consonant deletion and reduplication may be resolved as early as three years of age, whereas processes such as gliding and stopping of certain sounds may not be resolved until early school age. Amongst the hearing population phonological processes that are not resolved until beyond five years of age include; alveolarization, devoicing, depalatization, labialization, gliding of liquids and stridency deletion (Eriks-Brophy et al., 2013). It is encouraging that the participant group, who were on average 5.6 years at the time of testing, exhibited less of the early resolved processes compared to later resolved processes. For example, deaffrication is reported to be resolved in the normally hearing population by four years of age and was exhibited by 31% of participants compared to cluster reduction which is reported to be suppressed by five years of age was exhibited by 81% of the participants.

A small number of studies have described the pattern of phonological processes for groups of children using cochlear implants. Children using CIs have been reported as having both developmental and non-developmental processes which include consonant cluster reduction, stopping, fronting, diphthong simplification, assimilation, gliding, unstressed syllable deletion, initial consonant deletion, glottal replacement and vowel errors (Buhler et al., 2007; Chin & Pisoni, 2000; Flipsen & Parker, 2008; Grogan et al., 1995). An early study by Grogan et al. (1995) reported findings from
conversational speech samples of 10 children who received their CI between three and nine years of age. Speech samples were analyzed pre-implantation and at two years and six months post-implantation. Prior to implantation the most common phonological processes observed were elongation, nasalization, monophthongization for vowels, and voicing, stopping, deletion and cluster reduction for consonants. Reduction in the occurrence of several of the phonological processes was reported post-implantation but only deletion of consonants was reduced to a statistically significant degree. More recently, Buhler et al. (2007) reported findings from five children aged four who received their CI before three years of age. The children were assessed using a standardized test of articulation, the GFTA-2. Five phonological processes were present for all five participants: final consonant deletion, stopping, cluster reduction, simplification, liquid simplification and velar fronting. Results indicated that the participating children used a greater number of phonological processes and demonstrated less phonological skill than would be expected given their chronological age. This is a similar pattern of phonological processes as observed in the present study. Flipsen and Parker (2008) examined the phonological processes based on conversational samples of six children who received their CI before three years of age. The children ranged from 3.8 to 6.2 years at the time they were evaluated. Results identified the use of both developmental and non-developmental phonological processes in the children’s speech. The most frequently observed developmental processes included, consonant cluster reduction, stopping, liquid simplification, final consonant deletion, unstressed syllable deletion and fronting. Frequent non-developmental processes included vowel substitution, initial consonant deletion, vowel neutralization and diphthong simplification. Developmental patterns were used more often than non-developmental; however, the participants’ phonological systems were delayed compared to developmental expectations.

Most recently Eriks-Brophy et al. (2013) used the GFTA-2 to describe the speech production of 25 preschool children with hearing impairment and 35 peers with
normal hearing. Amongst the children with hearing loss, 10 used conventional HAs and 15 used a unilateral CI. The implanted children received their CI between nine months and four years and eight month of age. The children using HAs received them between one month and four years and five months of age. The children’s use of phonological processes was tracked over time and when possible was assessed at three, four and five years of age. Many of the phonological processes previously identified as being common for children with hearing loss were also observed in the participant group (including deletion of final consonants, consonant cluster simplification, devoicing of stops, stopping of fricatives and affricates, velar fronting and liquid simplification), although their use was not as prevalent as previous reports and declined as the children matured. For example, final consonant deletion (typically resolved at three years of age) was present at 36 month for the children with hearing impairment but was not observed at the 48 month interval; and cluster simplification (typically resolved by five years of age) was still present at 48 months but markedly reduced by 60 months. The children in the present study were only assessed at one particular time interval. It is, therefore, not possible to draw conclusions regarding the likelihood that the participant’s use of phonological processes will diminish as they mature. Long term follow up of the participant group could address this.

Lower incidence of phonological processes was associated with early identification of hearing loss and early HA fitting. Age at implantation was not related to the use of phonological processes. Children were also more likely to use less phonological processes if they used an AO mode of communication, had more highly involved parents and had higher non-verbal IQ. Use of more non-developmental processes was only associated with lower family participation which suggested that families play a significant role in keeping their children on a typical developmental path for speech production.
The reduced/limited number of non-developmental phonological processes observed for the participant group is promising from an intervention point of view. Dodd and Lacano (1989) have suggested that non-developmental processes may be less likely to normalize on their own and/or they may be less responsive to intervention.

This study examined speech production skills at only one assessment interval, around the time the children entered primary/elementary school. Studies using longitudinal designs have demonstrated the importance of measuring outcomes over time in order to track the developmental course and sequence of children’s speech production progression (Blamey, Sarant, et al., 2001; Serry & Blamey, 1999). Using only a standardized test of articulation also has its limitations by providing only limited opportunities for a child to produce a particular target phoneme and may not truly reflect children’s speech production abilities in a conversational capacity.

The shift towards children receiving CIs at progressively younger ages has provided these children the opportunity to develop superior speech production skills compared to their counterparts using HAs with profound hearing loss and children who have received their CI at a comparatively older age (e.g. over three years of age). Findings of the present study and others however, suggest that children who receive their CI before 2.5 years of age have delayed speech production skills compared to their hearing peers at the time they enter primary/elementary school. More long term is required to identify that this delay diminishes or is sustained as these children progress through their school years. Present knowledge on the speech production development of children using CIs, even if implanted before 12 months of age, supports close monitoring of this skill and, if a delay is identified, provision of habilitation to directly target areas of production requiring remediation.
9.5 Language

Mastery of language is essential for an individual to achieve communicative competence. Markman et al. (2011) stated that “language provides the tools to reveal ourselves to others in establishing and maintaining relationships and drives the perceptual learning that contributes to cognition” (p. 390). Reporting oral language outcomes for children using CIs is important due to the direct link to literacy and academic achievement, therefore describing language may also provide insight into subsequent vocational achievement.

The following section will describe the language skills of the participant group, discuss factors that impacted language development and make a comparison to the existing body of knowledge regarding the language development for children using CIs.

All participants made significant gains in receptive language development during the study duration. Rate of mean receptive language growth from pre-implantation to entry into primary/elementary school for the group was 1.04 (range 0.73 to 1.52) and was equivalent to the expected language growth for peers with normal hearing (1.0). Receptive language growth was not correlated with any of the predictive factors included in this study. The only factor that approached significance was non-verbal IQ ($r=0.34$, $p=0.05$). This suggested that all children in the present study were implanted early enough (CI before 2.5 years) to develop language at a rate equivalent to their peers with normal hearing. The rate of language growth for the participants in the present study was consistent with a number of past reports of children who received a CI in the first few years of life (Colletti et al., 2011; Connor et al., 2006; Holt & Svirsky, 2008; Leigh et al., 2013; Niparko et al., 2010; Svirsky et al., 2000).

Connor et al. (2006) provided some of the first evidence that early implanted children had the potential to develop age appropriate language skills. The study cohort
included 21 children who received their CI between one and 2.5 years of age and 15 children who received their CI between 2.6 and 3.5 years of age. The early implanted group demonstrated significantly greater rates of vocabulary growth for the first three years after implantation compared to children who received their implant after 2.5 years. Children who receive their CI before 2.5 years generally demonstrated growth in their receptive vocabulary that approximated those observed for children with normal hearing and were similar to the findings of the present study. Follow up was limited to three years post-implantation, however, the authors used the growth rates to predict the vocabulary score for children in each group at six years of age. It was predicted that children implanted before 2.5 years would fall within low-normal limits (standard score of 90) for a child with normal hearing at six years of age. Children implanted between 2.6 and 3.5 years were predicted to be more than one standard deviation below the mean (standard score of 79) for children with normal hearing at six years of age. Given the varying age at implantation for the participants there was an equally wide range of chronological ages for the children at the final data point. The resulting conclusion that children implanted between 2.6 and 3.5 years would have a language delay at six years of age whereas children implanted before 2.5 years would fall in the normal range was a prediction only and not based on an actual data point.

Holt and Svirsky (2008) described language abilities of 96 children who received their CIs up to four years of age. A notable addition to Holt and Svirsky (2008) compared to the study by Connor et al. (2006) was the inclusion of children who received a CI before 12 months of age. The children were separated into four groups based on the age they received their CI (6-12 months, 13-24 months, 25-36 months and 37-48 months). In general, the developmental trajectories of children implanted earlier were significantly better than those of children implanted later. The vast majority of children had delayed language skills, regardless of the age at which they received their cochlear implant(s); however, there was a trend for more children in the
younger age groups to perform within two standard deviations of the mean for children with normal hearing than for children in the older age groups. Follow up for this study was limited to two years post-implantation. So again, it is unclear if the positive language growth would be maintained over a longer period of time.

A subsequent study by Niparko et al. (2010) reported that the majority of children who received implants prior to age 18 months revealed trajectories of improvement that paralleled those of hearing controls. They also reported significantly higher rates of language comprehension and expression in children who received CI(s) before 18 months compared to children who received CI(s) between 18-36 months. Follow-up was limited to a three year period.

Duration of follow-up has been a key limitation of the above mentioned studies by Connor et al. (2006), Holt and Svirsky (2008) and Niparko et al. (2010). Colletti et al. (2011) addressed this issue with a study describing the language of children who received a CI as young as 2 months of age, 10 years after implantation. Colletti et al. (2011) reported that children who received a CI between 2-11 months exhibited progress in receptive language very close to children with normal hearing. The children in the 2-11 month group scored significantly better than those who received their CI between 12-23 months and 24-35 months at 10 years post-implantation.

A recent study to report on language growth rates for more than 30 children who received a CI between 6-12 months of age was completed by Leigh et al. (2013). This study expanded on the work of Dettman et al. (2007) six years earlier by including a larger number of children implanted between 6-12 months of age (n=32 compared to n=11) and 13-24 months of age (n=42 compared to n=30). The range of skills measured and period of follow up was also extended. In contrast to Dettman et al. (2007), the authors found no significant difference between the receptive language growth rate for the two groups of children. Both groups demonstrated growths rates
equivalent to peers with normal hearing. The difference reported between these two studies may be resolved by applying the language growth model discussed in the present study, which was also used by Leigh et al. (2013), to the data from Dettman et al. (2007). The younger group in the Dettman et al. (2007) study demonstrated language growth equivalent to their peers with normal hearing whereas the older children’s rate of receptive language growth was significantly poorer. Allowing for the larger language delays when implanted later would make the data from Dettman et al. (2007) consistent with the findings of Leigh et al. (2013). Leigh et al. (2013) did note a significant difference in the language delay exhibited between the two groups investigated when the children were assessed three years post-implantation. While the children who received their CI between 6-12 months, on average, demonstrated age appropriate receptive vocabulary skill, the children who received their CI between 13-24 months demonstrated a significant language delay.

The above mentioned studies are consistent with the present study by all demonstrating that populations of early implanted children have the potential to develop oral language at a rate equivalent (or similar) to peers with normal hearing. They do however, differ in the method used to compare groups of children using CIs. In some cases separation of the participants into groups based on their age at implantation appears arbitrary and raises the question as to whether similar results would be seen if the age boundaries where shifted in either direction by several months. The present study has addressed the potential limitation of categorizing the children based on age at implantation by using multiple regression analysis.

It is important to note that in the present study the calculation of receptive language slope has been made using two different assessments of receptive language skills, RI-TLS and PPVT. Both assessments provided age equivalent scores based on their respective normative samples. Age equivalent scores for each measure provided a common metric that facilitated combining information across the two measures and
enabled the calculation of language growth from pre-implantation through to school entry. There are however, notable differences between the two measurements that should be highlighted. The RI-TLS is a criterion referenced test; it is a checklist of skills based on parent report or observations. This type of evaluation (parent questionnaire) has its inherent flaws. Concerns have been raised regarding the reliability and validity of using parental reports for receptive language development (Thal et al., 1999; Tomasello & Mervis, 1994; Tomblin et al., 1989). Parental reports however, do provide a picture of day-to-day communication and acknowledge the parent as an important source of information. Dale et al. (1989) felt that advantages of parental reports outweigh the pitfalls. Use of performance based tests to assess the language of children before two years of age is extremely challenging. Difficulties exist due to the child’s ability to co-operate, attend and understand the language used during the test. The RI-TLS provides a reasonable alternative as it can be administered from birth, whereas norm referenced tests are rarely standardized below two years of age. RI-TLS has been used in a number of studies as a tool to describe the language of young children with hearing loss (Dettman et al., 2007; Meinzen-Derr, Wiley, Grether, & Choo, 2010; Nott, Cowan, Brown, & Wigglesworth, 2003).

The PPVT is a norm referenced, standardized test of receptive vocabulary. The PPVT has been used extensively to describe the language skills of children with hearing impairment. Although not ideal, there are precedents for combining age equivalent scores, across multiple language tests, in the literature to describe language growth over time [see Quittner et al. (2013)].

None of the factors included in this study were found to predict receptive language growth. This suggested that children (with characteristics equivalent to the participant group) implanted early enough (CI less than 2.5 years) have the potential to develop language at a rate equivalent to their normally hearing peers. Although a number of
studies have now described the language growth of early implanted children, few have included discussion of relevant covariates in addition to age at implantation.

The study previously described by Holt and Svirsky (2008) investigated the spoken language scores and rate of development for children who received an implant up to four years of age along with four covariates (unaided PTA, communication mode, gender and estimated family income) as a function of age at implantation. The authors concluded that earlier implantation led to better outcomes, however, noted few differences between children implanted between 6 and 12 months and those implanted between 13-24 months. This is consistent with the present study suggesting limited effect of age at implant below two years of age. The authors did also note that PTA and estimated family income accounted for some of the variance in receptive language between the groups. This is in contrast to the present study which found no effect of PTA or SES and is most likely the result of methodological differences between the two studies. Whereas, Holt and Svirsky have artificially categorized the children into age at implant groups the present study has not. The small number of participants (n=6) implanted before 12 months in Holt & Svirsky also makes it difficult to draw robust conclusions for this group.

Niparko et al. (2010) reported that greater residual hearing prior to implantation, higher ratings of parent-child interactions and higher SES were associated with greater rates of improvement in language comprehension and expression for children who received a CI up to five years of age. Direct comparison between the effects of covariates in this study compared to the present study cannot be made due to distinct differences in the participant demographics. Niparko et al. (2010) included children implanted up to five years of age, those with acquired or progressive hearing loss were not excluded and the children had more pre-operative residual hearing compared to the present study.
The findings for language growth in the present study and those of a number of studies reporting on the language growth of children who received early CIs were extremely promising. A body of evidence now exists that suggests that early implanted children have the potential to develop language at a rate equivalent to their peers with normal hearing through their preschool years and potentially beyond. Normal language growth however, does not imply age appropriate language and many children still exhibit a language delay (Holt & Svirsky, 2008; Leigh et al., 2013). Leigh et al. (2013) provided evidence that children implanted before two years of age had the potential to develop language at a rate equivalent to peers with normal hearing, however, the authors noted a significant difference in the language delay between children implanted between 6-12 months and those implanted between 13-24 months, with the children who received a CI between 6-12 months demonstrating smaller language delays. The significant difference in language delay was consistent across the two language measures used (RI-TLS and PPVT) by Leigh et al. (2013). The degree of language delay was positively correlated with the age the child received a cochlear implant.

Most recently, Dettman et al. (2016) reported on the receptive vocabulary skills of 207 children who received a CI before six years of age in a multicentre study. There were 207 children who completed the PPVT at school entry who were divided into five groups; 58 received their CI before 12 months of age, 33 received their CI between 13-18 months of age, 35 received their CI between 19-24 months of age, 52 received their CI between 25-42 months of age and 29 received their CI between 43-60 months of age. Group mean suggested that the children who received their CI before 12 months of age demonstrated age appropriate receptive vocabulary skills around the time they entered primary/elementary school. Of the children who received a CI before 12 months of age, 81% demonstrated vocabulary skills within the normal range compared to 52% of the children who received their CI between 13-18 months of age and 23% of the children who received their CI between 19-24 months of age.
This study further supports the findings of the present study and others who have suggested that the younger the child receives a CI the smaller the language delay and the greater the likelihood the child will enter primary/elementary school with age appropriate language.

Despite the positive gains all participants in the present study have made with their oral language growth, they all exhibited a language delay at the time they received their CI. This is most likely the result of the auditory deprivation experienced from having a bilateral profound hearing loss. Estimated age that oral language began developing for the participant group was derived by calculating individual regression lines based on age equivalent scores achieved on the RI-TLS pre-operatively and at 12 months post-implantation, and PPVT at two and three years post-implantation, and school entry. The formula for the regression line enabled the calculation of the intersection of the regression line with the x-axis, providing an estimate of the age at which language development began for the individual child. This is also equivalent to the distance of the individual participant’s language growth regression line from the normal development trajectory. This method of estimating the age at which oral language began developing for the individual child takes into account all available language data-points. The participants were only assessed once pre-operatively, with the assessment occurring on average 2.84 months (range 0.30 to 7.43 months) prior to implantation. As a result, pre-operative oral language progress made by the child may not be well represented by this method. An alternative and more evidentiary method would be to include multiple language data collection points pre-operatively, allowing the calculation of pre-operative oral language growth and post-operative oral language growth. This was not feasible due to the short duration between hearing loss diagnosis and implantation amongst the participant group. A method utilizing all available data points to calculate a single regression line was deemed the most appropriate.
Estimated age that oral language began developing was significantly correlated with age at identification of hearing loss, age at HA fitting, age at implantation and family participation rating. Sixty seven percent of the variance in language growth delay was accounted for by age at implantation. This is a noteworthy finding and highlights the importance of age at implantation for language delay. In the majority of the regression analyses performed in this study less than 30-40% of the variance was accounted for by multiple factors, let alone one individual factor. Researchers using multiple regression analysis to identify pertinent factors influencing speech perception and language outcomes for children with hearing impairment have rarely been able to account for greater than 40% of the variance in performance. For example, in a study of 47 children using cochlear implants, Blamey, Sarant, et al. (2001) accounted for 37% of the variance in language skills and less than 20% of the variance in speech perception scores when investigating the effect of age at onset of hearing loss, duration of deafness, device experience and pure-tone-average hearing loss. In one of the largest and most highly cited studies investigating the factors influencing language skills of children using CIs, Geers, Nicholas, et al. (2003) reported that child and family variables (age, age at implantation, age at onset of hearing loss, performance IQ, family size, SES and gender) accounted for 27% of the variance in total language score and that educational variables (e.g. mode of communication and family participation) accounted for an additional 7% of the variance. In context, in the present study, accounting for 67% of the variance in the estimated age that oral language began developing by age at implantation is a powerful finding and supports the provision of a CI as early as possible in order to minimise the language delay resulting from the period of auditory deprivation prior to implantation. For many of these children, born with profound bilateral hearing loss, oral language development does not begin effectively until they start receiving meaningful auditory input. This is further supported by the fact that 28 of the 32 participants in the present study obtained an age equivalent oral language score of zero at their pre-operative assessment. It should be noted, however, that findings of the present study are
restricted to the elements of oral language measured by the various language measures used. Obtaining an age equivalent score of zero on the RI-TLS suggests that the child did not meet the specified criteria to be categorized as having skills greater than zero, it does not imply that the child had no functional oral language.

As previously discussed, all children exhibited a measured language delay pre-operatively. By one year post-implantation 90% of the group were still exhibiting a language delay in comparison to hearing peers. This could be attributed to the fact that the children are “catching up” due to the language delay present pre-operatively. Language delay at one year post-implantation was correlated with age at implantation, family participation rating and non-verbal IQ. Together, age at implantation and non-verbal IQ accounted for 38.7% of the variance in receptive language delay and 47.4% of the variance in expressive language delay.

By two years post-implantation, 27 participants had reached a chronological age and/or developmental stage in which they were able to complete the PPVT. The mean standard score for PPVT was 81.8, which suggested that as a group the participants were just outside the normal range for their peers with normal hearing. At three years post-implantation 25 children had completed the PPVT and mean standard score had increased to 90.6, placing the group within the normal range for peers with normal hearing. This suggested that with longer duration of CI use the group were closing the gap in their receptive vocabulary skills and performing within the normal range for peers with normal hearing. The improvement in group mean over time also suggested that some participants were developing language at a rate greater that peers with normal hearing e.g. rate greater than 1.0. This result was further supported by the PPVT result obtained at school entry where again the participants as a group were achieving receptive vocabulary scores within the normal range for their peers with normal hearing (mean standard score 89.9).
PPVT standard score at two years post-implantation was significantly correlated with age at implantation (negative correlation), family participation rating and non-verbal IQ. Age at implantation was no longer significant when included in a regression analysis with non-verbal IQ suggesting that family participation and non-verbal IQ are the primary factors contributing to receptive vocabulary at two years post-implantation for the participant group. Non-verbal IQ was the only significant predictor of PPVT standard score at three years post-implantation. PPVT standard score at school entry was correlated with age at cochlear implantation (negative correlation), mode of communication, family participation and non-verbal IQ suggesting that those children with an early age at implantation, who used an AO mode of communication, had families rated as being more positively engaged in their intervention and had a higher non-verbal IQ, tended to have better receptive vocabulary scores at school entry. Age at implantation was not found to be significant when included in a multiple regression analysis. The variance in PPVT standard score at school entry was accounted for by family participation rating (25.5%), mode of communication (11%) and non-verbal IQ (10.7%). Across the three assessment intervals for which PPVT was used to measure receptive vocabulary, non-verbal IQ appears to be the most consistent predictor, however, when significant, family participation rating accounted for the greatest amount of variance in performance.

At school entry, the participants were further assessed using a more comprehensive evaluation of language; the PLS or CELF. In contrast to the PPVT which only assesses receptive vocabulary skills, the PLS and CELF provide measures of auditory comprehension and expressive language and total language. On average the participant group were performing within the normal range for all three metrics. There was however, variation in performance amongst the group. Only 55% of the group were performing within the normal range for auditory comprehension, 63% of the group were performing within the normal range for expressive language and 50% of the group were performing within the normal range for total language. This is
consistent with the recent finding of Dettman et al. (2016) who reported that 23-64% of children who received their CI up to two years of age had a total language score within the normal range on the CELF at the time they entered primary school.

Total language score for the participants in the present study was positively correlated with number of CIs (unilateral vs bilateral), mode of communication, family participation rating and non-verbal IQ. Multiple regression analysis suggested that 37.5% of the variance in total language was accounted for by bilateral implantation (17.2%) and non-verbal IQ (20.3%). Mode of communication and family participation rating were no longer significant when included in the multiple regression analysis.

The number of children exhibiting a language delay diminished over time. All participants demonstrated a language delay pre-operatively compared to 90% one year post-implantation and 50% at school entry. This is a positive finding, however, half the participant group still required ongoing intervention for language at the time they entered school, so there remains the need to address the factors influencing performance and remediate where possible. The most consistent predictor of language over time was non-verbal IQ, a factor that cannot be remediated with habilitation. Intervention needs to address the factors that can be influenced. For language, family participation and to some degree mode of communication should be the focus, however, age at implantation should not be overlooked.

Age at implantation appeared to have a diminishing effect on language over time. Age at implantation was significantly associated with the estimated age that oral language began developing, receptive and expressive language delay 12 months post-implantation, receptive vocabulary at two years post-implantation and at school entry. It was not associated with receptive vocabulary three years post-implantation or total language standard score at school entry for the participant group. Age at implantation was found to have only a weak effect on receptive vocabulary (PPVT)
and was not associated with PLS/CELF standard score at school entry. Despite this, the participants’ standard score on both the PPVT and PLS/CELF at school entry was negatively correlated with estimated age that oral language began developing, which suggested that those children with an older estimated age that oral language began developing tended to have poorer language scores at school entry. Two thirds of the variance in estimated age that oral language began developing was accounted for by age at implantation so it can be postulated that a younger age at implantation, which is associated with a reduced age that oral language begins developing, reduces the likelihood of delayed language at school entry. It is quite possible that language delay pre-implantation and in the early period post-implantation is primarily affected by age at implantation. As the child matures and their language progresses the influence of other covariates begins to increase, diminishing the relevance of age at implantation for children who received a CI before 2.5 years of age.

Sustained language delay that is not addressed will have significant implications for the child with hearing impairment as they progress through the school years. A number of previous studies have demonstrated that many children with severe-profound hearing loss, including those using CIs, have a four-to-five year delay in spoken language development by the time they enter secondary school (Blamey, Sarant, et al., 2001; Dahl et al., 2003; Davis & Hind, 1999; Ramkalawan & Davis, 1992; Sarant et al., 2009). For children with normal hearing, it is well established that poor spoken language ability is a primary cause of difficulty learning to read. It is, therefore, not surprising that literacy skills for children with hearing loss have been historically low with many not progressing their reading skills beyond fourth grade level of primary school (Geers, Tobey, Moog, & Brenner, 2008; Moeller, Tomblin, Yoshinaga-Itano, Connor, & Jerger, 2007). Vocabulary knowledge is essential for reading comprehension and expository writing (Geers & Hayes, 2011). The vocabulary advantage associated with early cochlear implantation, combined with improved phonological decoding made available by the CI, facilitates reading and
comprehension, resulting in more age appropriate literacy skills (Connor & Zwolan, 2004; Johnson & Goswami, 2010). Academic success relies heavily on reading and writing skills. Low literacy achievement and low academic outcomes will impact on the ability of the child with hearing loss to obtain meaningful employment as an adult.

In addition to academic and vocational success, delayed language has implications for the social and emotional development of children with hearing impairment. A significant association has been found between speech perception, production and language skills and the level of social wellbeing in children with CIs (Dammeyer, 2010; Percy-Smith et al., 2008). Delayed language development, including limited vocabulary, and deficits in knowledge of grammar and age-appropriate slang may lead to pragmatic problems (Sarant, 2012). It has previously been reported that children with CIs often have limited pragmatic skills, which can lead to poor social integration (Bat-Chava, Martin, & Kosciw, 2005). Children with poor pragmatic skills may say inappropriate things during conversations, may show little variety in the language they use, or may relate stories in a disorganised, illogical way (Sarant, 2012). These behaviours often lead to a higher incidence of communication breakdown, can lower social acceptance and result in isolation. Markman et al. (2011) also summarised the long term implications of language delay for children using CIs and suggested that without access to the sounds of speech through hearing technology children with SNHL face challenges in their cognitive and psychosocial development and academic performance. Citing the works of Summerfield and Marshall (1999) and Cheng et al. (2000), Markman et al. (2011) further stated that “together, such cascading consequences carry downstream implications for employment and quality of life” (p.389). Minimizing, or ideally eliminating, language delay for children using CIs is therefore paramount to reduce the negative global and long term ramifications a language delay can have on the individual child’s life.
It should be highlighted that there are some limitations to the language measures used in the present study. While standardized assessments such as the PLS/CELF and PPVT measure a child’s development against a cohort of peers and indicate areas for intervention, they may not identify the specific language structures/domains (e.g., morphology vs syntax) that require intervention or tell us what the child understands when communicating with other people (Paul, 2007). Ideally standardized tests should be used in conjunction with other language measures such as audio-visual recording of functional communication and parental report (Yoshinaga-Itano, 1994). Audio-visual recording of functional communication was not included in the present study due to the time consuming nature of the analysis required. Given the large number of participants and longitudinal nature of the present study it was not considered feasible or necessary. The present study did not aim to develop specific intervention goals for individual children so the additional detail that analysis of audio-visual recording of functional communication would have provided did not warrant the time commitment required.

The extensive use of the PPVT in the present study could be open to criticism. The PPVT is a somewhat simplistic evaluation of language as it only measures one aspect of language; receptive vocabulary skills. It could be argued that this not a broad enough measure to make any global claims regarding language at a particular point in time or over a period of time. The PPVT has however, been demonstrated to be strongly correlated with more comprehensive evaluations of language that take far longer to administer (Ching et al., 2010). In the present study PPVT at two and three years post-implantation and at school entry were highly correlated (refer to Appendix 8) with the PLS/CELF administered at school entry, further supporting the validity of using PPVT as a robust measure of describing receptive language progress over time.
9.6 Summary of findings

The present study provided a comprehensive description of the child and family characteristics of a group of 32 children who received their CI before 2.5 years. As hypothesized, earlier identification of hearing loss led to earlier implantation. The group was, on average, from SES advantaged areas, had highly educated mothers and had families that were highly engaged in their intervention compared with the general population. There was a preference for an AO communication approach suggesting that spoken language was a primary focus for most families. Non-verbal IQ for the participant group was equivalent to the distribution for normally hearing peers.

The participant’s speech perception, speech production and language was prospectively assessed pre-implantation and at several intervals post-implantation until the child entered primary/elementary school. The prospective longitudinal assessment battery enabled a comprehensive description of these domains of communication to be completed. Children who received their CI before 2.5 years were able to achieve speech perception skills that, on average, surpassed their adult counterparts with post-lingual hearing loss using CIs. Speech perception skills for the participant group were superior to previous published reports for children who received CIs at older ages. All children developed intelligible speech, although speech production skills were found to be quite variable and were delayed compared to peers with normal hearing. On average, the children who received a CI before 2.5 years of age developed language at a rate comparable to normally hearing peers. All children demonstrated a language delay prior to implantation, most likely attributed to the auditory deprivation experienced as a result of having a profound bilateral hearing loss. By the time they entered primary/elementary school, half the group was achieving language skills within the normal range for peers with normal hearing.
Age at implantation played a significant role in language delay at the time the children received their CI. Younger age at implantation continued to be associated with superior language as the children matured, although the effect diminished over time as other covariates became more relevant. Age at implantation was significantly associated with speech production skills but was not associated with speech perception skills at the time the children entered primary/elementary school.

One of the most consistent predictors of performance over time, within and across communication domains investigated was non-verbal IQ. Cognitive delay has been previously found to be associated with slower development of speech perception, speech production and language skills after cochlear implantation (Isaacson et al., 1996; Palmieri et al., 2014; Pyman et al., 2000; Waltzman et al., 2000). Mayne, Yoshinaga-Itano, Sedey, and Carey (2000) suggested that non-verbal IQ was the strongest predictor of language outcomes for children with hearing loss up to the age of five years. The studies by Isaacson et al. (1996), Pyman et al. (2000), Waltzman et al. (2000) and those reviewed by Palmieri et al. (2014) all included children with a diagnosed disability in addition to hearing loss. The present study highlights the importance of non-verbal IQ in children with normal-borderline intelligence and no additional diagnosis. This finding suggests that cognitive factors play a significant role in speech and language development in children with hearing impairment who have not been diagnosed with developmental delay. This finding is consistent with that of Moog and Geers (2003) who suggested “that the underlying cognitive processing strategies employed by a given child may greatly influence their ability to use the degraded signal provided by an implant to understand and produce spoken language” (p.123).

Family participation also played a significant role in the speech perception, speech production and language skills of the participants. The association of family participation with all three areas of communication investigated suggested that this
factor may be equally or more relevant than age at implantation for this population of children implanted before 2.5 years of age and is consistent with a recent report by Quittner et al. (2013). In a large study evaluating the oral language development of 188 children who received their CI before five years of age, Quittner et al. (2013) evaluated the quality of the parent-child interactions in the domains of maternal sensitivity, cognitive stimulation and linguistic stimulation. Quittner et al. (2013) reported that the magnitude of effects for maternal sensitivity and cognitive stimulation on the growth of language was similar to the effect of age at implantation. In addition, Szagun and Stumper (2012) suggested that for early implanted children, their home language environment had a greater impact on their language progress than age at implantation. Two earlier studies have also highlighted the importance of family participation for the language development of children with hearing impairment using the same methodology for categorizing family participation as used in the present study (Moeller, 2000; Sarant et al., 2009). The significant finding for family participation in the present study, in addition to these previous reports, suggested that the best outcomes are achieved when there is strong family involvement in the child’s learning. It also highlights the importance of addressing family participation in intervention programs to enable children to achieve optimal language outcomes.

SES and maternal education appeared to have little influence on any of the outcome measures in the present study. The relevance of these two variables for the language learning of both children with normal hearing and those with a hearing impairment has received significant attention in the literature with no clear consensus. Two large studies investigating the importance of age at implantation on the language of children with CIs found a significant effect for SES (Holt & Svirsky, 2008; Niparko et al., 2010). Failure to find a significant result for these two factors in the present study does not suggest that they do not influence outcomes amongst the broader population of children using cochlear implants. Participant numbers in the present study were relatively small compared to the above mentioned studies by Holt and
Svirsky (2008) (n=97) and Niparko et al. (2010) (n=188). Distribution of SES for the participant group in the present study was positively skewed with the majority of participants living in SES advantaged areas. It is possible that with greater participant numbers or greater diversity in SES the influence of SES may have been different. Equally, range of age at implantation in the present study was significantly lower than for the studies by Holt and Svirsky (2008) (age at implantation up to four years) and Niparko et al. (2010) (age at implantation up to five years), it may be the case that SES is more relevant for older children where the emphasis is placed on remedial work rather than optimizing that natural progression of speech and language skills. A recent study by Cuda, Murri, Guerzoni, Fabrizi, and Mariani (2014) found a significant effect for maternal education on the language skills of early implanted children. In the study by Cuda et al. (2014), 53% of the mothers had a tertiary education, 40% had completed secondary school and the remaining two mothers had not completed secondary school. In contrast, in the present study, 94% of the mothers had a tertiary education. The lack of diversity in maternal education in the present study made it difficult to interpret the relevance of this factor; greater diversity may have resulted in a significant finding. Maternal education, its potential underlying mechanisms (e.g. maternal IQ) and implications for child language development for children with hearing impairment warrants further investigation. The suggestion by Quittner et al. (2013) that maternal education may be related to the quality and quantity of communicative input received by children in their home environment needs to be explored to reveal the underlying mechanisms. Maternal education cannot be directly targeted in intervention programs; however, the positive language modelling behaviors used by highly educated mothers could well be a focus of early intervention.

Pre-operative hearing level was not a significant predictor of any of the outcomes measured in the participant group. The present study was designed with the intention of controlling for the relative influence of this factor by excluding children with 3FPTA
better than 90dBHL. It is well documented that children with residual hearing in the
severe hearing loss range can make significant gains in speech and language
development with the use of conventional HAs. Although it has been demonstrated
that children with hearing thresholds in the severe range can benefit from cochlear
implantation in one or both ears (Leigh et al., 2011), the evidence supporting the
provision of an early CI may be less relevant for children with greater amounts of
residual hearing; these children may begin making good progress with their language
development using conventional HAs.

AO mode of communication was associated with superior speech perception
performance, speech production and language at the time the children entered
primary/elementary school. Mode of communication was not associated with speech
perception or language skills at any of the earlier assessment intervals. This
suggested that the benefit of exposure to an AO only language model only became
evident after a sustained period of time, e.g. around the time that the child enters
primary/elementary school. Much of the previous literature investigating the role of
mode of communication on the speech and language development of children using
CIs has included children with a broad range of age at implantation making
comparison with the present study difficult. One recent study that warrants
comparison and had consistent findings with the present study was completed by
Dettman et al. (2013). Dettman et al. (2013) reported superior speech perception
and language abilities for children, assessed at approximately five years of age,
enrolled in AO education settings. In contrast, Yanbay et al. (2014) found no
significant difference in language scores between children using CIs enrolled in
education programs emphasizing spoken language compared to signed
communication once the effects of potential covariates (age at diagnosis of hearing
loss and family involvement) were accounted for. The lack of consensus in the
literature regarding the relevance of mode of communication and the interaction with
covariates highlights the complexity of the relationship. Perhaps it is the quality of the
language model rather than the mode that should be the focus of intervention for children who receive an early cochlear implant.

On average, the participants developed language at a rate equivalent to their normally hearing peers; they did, however, demonstrate a language delay closely related to their age at implantation. This finding supported the provision of a CI at the earliest opportunity in order to minimise the impact of this language delay.
10 CONCLUSION

Findings of the present study supported the growing body of evidence in the literature suggesting that early implantation can lead to oral language acquisition that is equal to peers with normal hearing. On average, the participants in the present study developed oral language at a rate equivalent to their peers with normal hearing. They did, however, demonstrate a language delay closely related to the age they received their CI, a finding which was sustained for the duration of the study. Speech production skills were also directly affected by the age the child received their CI, with the group on average demonstrating delayed skills compared to peers with normal hearing. All participants developed significant open-set speech perception skills which were not significantly related to the age they received their CI.

With the acceptance of the benefits of early implantation, there should be an appropriate shift in focus to the barriers to early implantation; a topic that is emerging in the literature. At the commencement of the present study approximately 30% of newborns in Victoria were screened for hearing loss. This had reached greater than 99% coverage by the conclusion of the study. This shift in coverage may further reduce the age at implantation for children in the state of Victoria and as a result more children will have the potential to obtain the benefits demonstrated by the participant group. Unfortunately many children with pre-lingual severe-to-profound hearing loss worldwide are not receiving CIs in a timely manner. There are potential obstacles to early implantation such as medical comorbidities, parental acceptance of the hearing loss, SES and financial status (public funding vs private health insurance) that may delay implantation. Parental attitudes toward cochlear implantation and language barriers are also likely causes for delayed cochlear implantation. Until these issues are addressed many children will continue to receive a CI well into the second
or third year of life. It is paramount that families and policy makers understand the potential adverse effect of undue delays in cochlear implantation.

Non-verbal IQ, family participation and, to a lesser degree, mode of communication were also found to have significant influence on the communication outcomes of the participants. Higher non-verbal IQ was associated with better language, speech production and speech perception skills. Non-verbal IQ cannot be directly targeted in intervention. Awareness of the association with outcomes can, however, assist with counselling regarding expectations for outcome and the ongoing level of support an individual child may (or may not) need as they progress through the education system. Family participation rating and age at implantation were significantly associated with one another. Both factors explained a significant amount of variance in the language and speech production skills of the participants. These findings point to the importance of both variables and to the strong contribution that families make to outcomes for children. The finding for family participation suggests that strong levels of family involvement may buffer the effects of a later age at CI to some degree. The significant findings for family participation also suggested that CI programs, which typically provide rehabilitation focused on speech and language training, would likely see improved outcomes by incorporating maternal sensitivity/family participation training into their programs.

Mode of communication had some degree of influence on all outcome measures at school entry. It appeared that children using an AO mode of communication performed better on all measures. Proving causality, however, is challenging and beyond the scope of this study. There are two scenarios that are plausible. It may be that using a communication mode that emphasizes spoken language and listening results in better outcomes. Alternately, families of children who are performing more poorly chose to supplement their communication with sign language. The relationship may also be far more complex.
Major strengths of the present study were the prospective nature of the data collection and characteristics of the participant group. The group was homogeneous in terms of the onset and degree of deafness (all congenitally severe-to-profoundly hearing impaired), absence of a greater than borderline developmental delay or significant co-morbidity, basic family characteristics (English speaking and parents with normal hearing) and the assessment battery administered. Through sample selection, this created the ability to focus on variables of interest by reducing the effect of confounding factors. This does, however, reduce the generalizability of the findings to a degree. The conclusions may be appropriately generalized to children who share or approximate characteristics of the participant group. It is believed, however, that the participant group are representative of a large proportion of the current generation of children receiving CIs in Australia.

The present study provides compelling evidence that a CI should be offered as young as possible in order to minimise language delay, provided the child meets the audiological candidacy guidelines, and other medical and otological issues have been considered.
11 LIST OF ASSOCIATED PUBLICATIONS AND PRESENTATIONS


implants. Paper presented at the Newborn Hearing Screening (NHS) 2008, Cernobbio (Lake Como), Italy.


12 BIBLIOGRAPHY/REFERENCES


Geers, A., & Hayes, H. (2011). Reading, writing, and phonological processing skills of adolescents with 10 or more years of cochlear implant experience. [Research Support, N.I.H., Extramural]. *Ear and Hearing, 32*(1 Suppl), 49S-59S.


Zwolan, T. A., Ashbaugh, C. M., Alarfaj, A., Kileny, P. R., Arts, H. A., El-Kashlan, H.
K., & Telian, S. A. (2004). Pediatric cochlear implant patient performance as a

Zwolan, T. A., Zimmerman-Phillips, S., Ashbaugh, C. J., Hieber, S. J., Kileny, P. R., &
APPENDIX 1: CONVERTING LIVE CNC SCORES TO RECORDED

Speech perception performance on a monosyllabic word test for children, using cochlear implants, in a (controlled) live-voice condition versus presented using a loudspeaker has been shown to be significantly different (Dettman, 2016, personal communication, March 31). Dettman (2016, personal communication, March 31) provided a predictive function which yielded the pre-recorded score based on the live-voice score. The associated statistical analysis for this prediction is provided below.

Paired T-Test and CI: CNC/ph/L, CNC/ph/R

Paired T for CNC/ph/L - CNC/ph/R

<table>
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<th>N</th>
<th>Mean</th>
<th>StDev</th>
<th>SE Mean</th>
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<td>41</td>
<td>84.15</td>
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</table>

95% CI for mean difference: (4.23, 10.27)
T-Test of mean difference = 0 (vs ≠ 0): T-Value = 4.85  P-Value = 0.000

Paired T-Test and CI: CNC/wd /L, CNC/wd/R

Paired T for CNC/wd /L - CNC/wd/R

<table>
<thead>
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<th>N</th>
<th>Mean</th>
<th>StDev</th>
<th>SE Mean</th>
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<td>65.41</td>
<td>22.29</td>
<td>3.48</td>
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<tr>
<td>Difference</td>
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<td>13.29</td>
<td>15.91</td>
<td>2.48</td>
</tr>
</tbody>
</table>

95% CI for mean difference: (8.27, 18.31)
T-Test of mean difference = 0 (vs ≠ 0): T-Value = 5.35  P-Value = 0.000

Regression Analysis: CNC/ph/R versus CNC/ph/L

The regression equation is
CNC/ph/R = 14.38 + 0.7430 CNC/ph/L

S = 9.01511  R-Sq = 56.4%  R-Sq(adj) = 55.3%

Analysis of Variance

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<th>Source</th>
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<th>MS</th>
<th>F</th>
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</tbody>
</table>
Regression Analysis: CNC/wd/R versus CNC/wd /L

The regression equation is
CNC/wd/R = 10.52 + 0.6360 CNC/wd /L

S = 13.8566   R-Sq = 51.8%   R-Sq(adj) = 50.5%

Analysis of Variance

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>P</th>
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<td>8042.2</td>
<td>8042.18</td>
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<td>39</td>
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<td>192.01</td>
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<td>40</td>
<td>15530.4</td>
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APPENDIX 2: FAMILY PARTICIPATION RATING SCALE

COCHLEAR IMPLANT CLINIC
Moeller’s Family Participation Rating Scale

The use of this rating scale is an attempt to characterize the quality/level of family participation that is occurring for individual children who attend the Cochlear Implant Clinic. Two members of staff who have recently worked directly with the families involved should assign a rating to describe the level of family involvement.

To aid this process, there is a verbal case description which represents each rating of 1 to 5. On this continuum, a rating of 1 represents limited involvement (far below average). A rating of 5 represents ideal involvement. You will notice on the rating form there is a place to indicate how well you recall the family (eg, you are indicating how confident you feel in assigning a rating). You are asked to indicate if your recall is good, okay, or questionable. If you believe that you are not familiar enough with a particular family, then do not assign a rating at all.

Rating Scale Descriptors

Rating of 5 (Ideal Participation)
Family seems to have made a good adjustment to the child’s deafness. The family is able to put the child’s disability in perspective within the family. Family members actively engage in sessions. They attend sessions and meetings regularly and pursue information on their own. They serve as effective advocates for their child with professionals and service organisations etc. Family members become highly effective conversational partners with the child and serve as strong and constant language models. Family members become fluent/effective users of the child’s mode of communication. They are capable of applying techniques of language expansion. Extended family members are involved and supportive.

Rating of 4 (Good Participation)
Family members make a better than average adjustment to the child’s deafness. Family members regularly attend parent meetings and sessions. Parents take an active role in Family Support Service Plans and Parent Conferences. Family members serve as good language models for the child and make an effort to carry over techniques at home. Some family members have fairly good facility in the child’s communication mode and/or in techniques for language stimulation. Efforts are made to involve extended family members.

Rating of 3 (Average Participation)
Family is making efforts to understand and cope with the child’s diagnosis. Family members participate in most sessions/meetings. Busy schedules or family stresses may limit opportunities for carryover of what is learned. Family may find management of the child challenging. Family attends Family Support Service Plans and Parent Conferences but may rely primarily on professional guidance. Family attempts to advocate but may be misdirected in some of their efforts. Selected family members (eg, mother) may carry more than their share of responsibility for the child’s communicative needs. Family members develop at least basic facility in child’s communication mode. Family members are willing to use language expansion techniques but need ongoing support and direction.
Rating of 2 (Below Average)
Family struggles in acceptance of the child’s diagnosis. The family may be inconsistent in attendance. They may be inconsistent in maintaining the hearing aids and keeping them on the child outside of school. They may have some significant life stressors that interfere with consistent carryover at home. Management of the child presents daily challenges to the family. Communicative interactions with the child are basic. Family lacks fluency in the child’s mode of communication.

Rating of 1 (Limited Participation)
Family faces significant life stresses that may take precedence over the child’s needs (eg, domestic abuse, homelessness). Family has limited understanding of deafness and its consequences for the child. Participation may be sporadic or less than effective. Parent/child communication is limited to very basic needs.

Date:

Child’s Name: ________________________________

Staff Member’s Name: ________________________________

Confidence in Rating: (please circle)  Good   Okay   Questionable

Rating (please circle)  1  2  3  4  5
### APPENDIX 3: FAMILY & EDUCATIONAL CHARACTERISTICS QUESTIONNAIRE

**COCHLEAR IMPLANT CLINIC**

**Family & Educational Characteristics Questionnaire**

Child Name: _______________________________  DOB: ____________

Person completing questionnaire: _______________  Date: ____________

**Assessment point:**
- Pre-op  [ ]
- Post-implantation  [ ]
- ________ (i.e. 2 years post-implantation)

**Parents hearing status:**
- Mother ____________________  Father ____________________

**Family details:**
- Mother living with child  yes/no
- Father living with child  yes/no
- No. of siblings  _____
- Position of hearing impaired child in family i.e. oldest child  ________________
- Primary care giver to the child  ______________________________
- Primary language of the home  ________________________________
- Secondary language of the home  ________________________________

**Postcode:** (where child lives)  ________________

**Child’s participation in family life:**
Rate child's involvement in these home activities. “often” would mean the child engages in these activities more than once a week. Select “NA” if not appropriate given the child's age.

<table>
<thead>
<tr>
<th></th>
<th>Accompanies family members on errands (e.g. supermarket shopping)</th>
<th>Visits library and chooses books</th>
<th>Plays games with the rest of the family</th>
<th>Plays with friends with normal hearing outside of school/kinder</th>
<th>Plays with friends with hearing impairment outside of school</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>often  weekly  monthly  rarely  never  NA</td>
<td>often  weekly  monthly  rarely  never  NA</td>
<td>often  weekly  monthly  rarely  never  NA</td>
<td>often  weekly  monthly  rarely  never  NA</td>
<td>often  weekly  monthly  rarely  never  NA</td>
</tr>
<tr>
<td>1</td>
<td></td>
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<td>2</td>
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<td>4</td>
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<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

6. Reads with family member
LEIGH: Communication outcomes for early CI

<table>
<thead>
<tr>
<th></th>
<th>often</th>
<th>weekly</th>
<th>monthly</th>
<th>rarely</th>
<th>never</th>
<th>NA</th>
</tr>
</thead>
</table>
7. Prepares food with family member |
|          | often | weekly | monthly | rarely | never | NA |
8. Makes things or does hobby-type projects with a family member |
|          | often | weekly | monthly | rarely | never | NA |
9. Joins in family outings (e.g. to zoo, movies, playgrounds etc) |

Educational setting:
Mode of communication* (see explanation below) used at home __________________________

Does the child attend the following?
1. Early intervention yes/no
   If yes,
   Name of centre/program (i.e. Taralye, Aurora etc) __________________________
   Hours per week of individual sessions __________________________
   Mode of communication used in individual therapy __________________________
   Hours per week of group sessions __________________________
   Mode of communication used in group sessions __________________________
2. Kindergarten yes/no
   If yes,
   Hours per week __________________________
   Mode of communication __________________________
3. Childcare/Crèche yes/no
   If yes,
   Hours per week __________________________
4. Other. Please describe (i.e. Grandmother minds child 2 days per week)
   __________________________

If you would like any assistance completing this form, please contact your child’s case manager on Ph: 9929 8624, Fax: 9929 8625 or email: cic@eyeandear.org.au

*Mode of communication description (adapted from Geers & Brenner, 2003):
0. informal gesture
1. sign only used for the majority of communication
2. speech and sign (speech occurring simultaneously with each signed word. Speech only or sign only used rarely)
3. speech only used for the majority of communication with occasional signing.
4. speech emphasis with manual cues/ued speech used to enhance lip-reading
5. auditory-oral (child is encouraged to listen and lip-read)
6. auditory-verbal (emphasis is on listening alone)
### APPENDIX 4: CLASSIFICATION OF PHONOLOGICAL PROCESSES (BARDLEY, 2010)

<table>
<thead>
<tr>
<th>Process</th>
<th>Description</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alveolar Backing</td>
<td>An alveolar consonant is replaced with a more posterior consonant</td>
<td>Non-Developmental</td>
</tr>
<tr>
<td>Affrication</td>
<td>A non-affricate consonant is replaced with an affricate consonant</td>
<td>Non-Developmental</td>
</tr>
<tr>
<td>Assimilation</td>
<td>A phoneme is replaced by another target phoneme in the same word</td>
<td>Developmental</td>
</tr>
<tr>
<td>Cluster Deletion</td>
<td>Deletion of an entire cluster in a word</td>
<td>Developmental</td>
</tr>
<tr>
<td>Cluster Error</td>
<td>A consonant in a cluster has been replaced with a different consonant</td>
<td>Developmental</td>
</tr>
<tr>
<td>Cluster Reduction</td>
<td>Reduction in the number of consonants in a cluster</td>
<td>Developmental</td>
</tr>
<tr>
<td>Consonant Insertion</td>
<td>Insertion of an additional consonant in a word</td>
<td>Non-Developmental</td>
</tr>
<tr>
<td>Deaffrication</td>
<td>An affricate consonant becomes a fricative consonant</td>
<td>Developmental</td>
</tr>
<tr>
<td>Denasalisation</td>
<td>A nasal consonant is replaced with an oral consonant</td>
<td>Non-Developmental</td>
</tr>
<tr>
<td>Devoicing</td>
<td>A voiced consonant is replaced with a voiceless consonant</td>
<td>Non-Developmental</td>
</tr>
<tr>
<td>Diphongization</td>
<td>A monophthong is replaced with a diphthong</td>
<td>Non-Developmental</td>
</tr>
<tr>
<td>Elongation</td>
<td>A short monophthongs is replaced with a long monophthong</td>
<td>Non-Developmental</td>
</tr>
<tr>
<td>Final Consonant Deletion</td>
<td>Deletion of the final single consonant of a word</td>
<td>Developmental</td>
</tr>
<tr>
<td>Frication</td>
<td>A non-affricate, non-fricative consonant is replaced with a fricative</td>
<td>Non-Developmental</td>
</tr>
<tr>
<td>Process</td>
<td>Description</td>
<td>Classification</td>
</tr>
<tr>
<td>---------------------------------</td>
<td>---------------------------------------------------------------</td>
<td>-------------------------</td>
</tr>
<tr>
<td>Gliding of Fricatives</td>
<td>A fricative is replaced with a glide</td>
<td>Developmental</td>
</tr>
<tr>
<td>Gliding of Liquids</td>
<td>A liquid is replaced with a glide</td>
<td>Developmental</td>
</tr>
<tr>
<td>Glottal Insertion</td>
<td>A glottal stop is inserted in a word</td>
<td>Non-Developmental</td>
</tr>
<tr>
<td>Glottal Replacement</td>
<td>Replacement of a consonant with a glottal stop</td>
<td>Non-Developmental</td>
</tr>
<tr>
<td>Initial Consonant Deletion</td>
<td>Deletion of the initial single consonant of a word</td>
<td>Non-Developmental</td>
</tr>
<tr>
<td>Lisping</td>
<td>A ‘s’ becomes ‘th’ (voiceless) or ‘z’ becomes ‘th’ (voiced)</td>
<td>Developmental</td>
</tr>
<tr>
<td>Metathesis</td>
<td>Two phonemes within a word are swapped. Both are correctly produced</td>
<td>Non-Developmental</td>
</tr>
<tr>
<td>Migration</td>
<td>Movement of a phoneme to a new position in the same word</td>
<td>Non-Developmental</td>
</tr>
<tr>
<td>Monophthongization</td>
<td>A diphthong is replaced by a monophthong</td>
<td>Non-Developmental</td>
</tr>
<tr>
<td>Nasalisation</td>
<td>An oral consonant is replaced with a nasal consonant</td>
<td>Non-Developmental</td>
</tr>
<tr>
<td>Other Backing</td>
<td>A consonant is replaced with a more posterior consonant, excluding Alveolar Backing</td>
<td>Non-Developmental</td>
</tr>
<tr>
<td>Other Consonant Deletion</td>
<td>Deletion of a single consonant, excluding Initial Consonant Deletion and Final Consonant Deletion</td>
<td>Non-Developmental</td>
</tr>
<tr>
<td>Other Fronting</td>
<td>A consonant is replaced with a more anterior consonant, excluding Velar Fronting and Palatal Fronting</td>
<td>Developmental</td>
</tr>
<tr>
<td>Overstressed</td>
<td>Schwa is replaced with another vowel</td>
<td>Non-Developmental</td>
</tr>
<tr>
<td>Palatal Fronting</td>
<td>A palatal consonant is replaced with an alveolar consonant</td>
<td>Developmental</td>
</tr>
<tr>
<td>Process</td>
<td>Description</td>
<td>Classification</td>
</tr>
<tr>
<td>-----------------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>Reduplication</td>
<td>A word is replaced by two or more identical syllables</td>
<td>Developmental</td>
</tr>
<tr>
<td>Shortening</td>
<td>A long monophthong is replaced with a short monophthong</td>
<td>Non-Developmental</td>
</tr>
<tr>
<td>Stopping of Fricatives</td>
<td>A fricative or affricate consonant is stopped</td>
<td>Developmental</td>
</tr>
<tr>
<td>Stopping of Liquids</td>
<td>A liquid is stopped</td>
<td>Non-Developmental</td>
</tr>
<tr>
<td>Substitution</td>
<td>Phonemic or diacritic change not covered by enabled phonological process</td>
<td>Non-Developmental</td>
</tr>
<tr>
<td>Syllable Deletion</td>
<td>Deletion of a syllable in a word</td>
<td>Non-Developmental</td>
</tr>
<tr>
<td>Syllable Insertion</td>
<td>Insertion of a syllable in a word (frequently schwa insertion; epenthesis)</td>
<td>Non-Developmental</td>
</tr>
<tr>
<td>Unintelligible</td>
<td>Unintelligible word or babble. No target word was available for transcription</td>
<td>Non-Developmental</td>
</tr>
<tr>
<td>Velar Fronting</td>
<td>A velar consonant is replaced with an alveolar consonant</td>
<td>Developmental</td>
</tr>
<tr>
<td>Voicing</td>
<td>A voiceless consonant is replaced with a voiced consonant</td>
<td>Non-Developmental</td>
</tr>
<tr>
<td>Vowel Reduction</td>
<td>A vowel (excluding schwa) is replaced with a schwa</td>
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<tr>
<td>Weak Syllable Deletion</td>
<td>Deletion of an unstressed syllable in a word</td>
<td>Developmental</td>
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APPENDIX 5: MATRIX OF CORRELATIONS: PREDICTOR FACTORS

Pearson correlation (r) and p-values provided for each correlation. Value for r is represented above and p-value represented below.

<table>
<thead>
<tr>
<th></th>
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<th>Age at HA</th>
<th>Age at CI</th>
<th>No. of CIs</th>
<th>Mode of Communication</th>
<th>Best 3FPTA</th>
<th>Family Rating</th>
<th>Mat Ed</th>
<th>SES Rating</th>
<th>Birth order</th>
<th>Family size</th>
<th>Gender</th>
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<td>Age at CI</td>
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</tbody>
</table>

Pearson correlation (r) and p-values are provided for each correlation. Value for r is represented above and p-value represented below.
APPENDIX 6: CONVERSION OF LIVE SPEECH PERCEPTION SCORE TO PREDICTED PRE-RECORDED SCORES

Speech perception scores: Raw scores obtained in the live condition adjusted using the predictive function described in Appendix 1.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Condition</th>
<th>Raw score CNCph</th>
<th>Raw score CNCw</th>
<th>Adjusted score CNCph</th>
<th>Adjusted score CNCw</th>
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<td>64</td>
<td>87</td>
<td>64</td>
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<tr>
<td>2</td>
<td>Recorded</td>
<td>92</td>
<td>80</td>
<td>92</td>
<td>80</td>
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<tr>
<td>3</td>
<td>Recorded</td>
<td>90</td>
<td>72</td>
<td>90</td>
<td>72</td>
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<tr>
<td>4</td>
<td>Recorded</td>
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<td>91</td>
<td>76</td>
<td>91</td>
<td>76</td>
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<td>6</td>
<td>Recorded</td>
<td>94</td>
<td>84</td>
<td>94</td>
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<td>7</td>
<td>Live</td>
<td>85</td>
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<td>8</td>
<td>Live</td>
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APPENDIX 7: MATRIX OF CORRELATIONS: PREDICTORS WITH OUTCOMES MEASURES

Pearson correlation (r) and p-values provided for each correlation. Value for r is represented above and p-value represented below.

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APPENDIX 8: MATRIX OF CORRELATIONS: OUTCOME MEASURES

Pearson correlation (r) and p-values provided for each correlation. Value for r is represented above and p-value represented below.

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<th>RI-TLS 12mo Post-implantation Expression delay</th>
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<th>PPVT SS @ 2yrs post</th>
<th>PPVT delay @ 3yrs post</th>
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<th>PPVT delay @ school entry</th>
<th>PPVT SS @ school entry</th>
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Author/s:
LEIGH, JAIME

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Communication outcomes for children who receive a cochlear implant before 2 1/2 years of age

Date:
2015

Persistent Link:
http://hdl.handle.net/11343/91561

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