Speech Profile of School-age Children with Hearing Loss in Comparison to Children with Normal Hearing in New Zealand

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Abstract

Aims: Aims of doctoral thesis were to: 1) describe the phonetic inventory of New Zealand English (NZE) of early school-age children with mild-to-profound HL in comparison to their peers, 2) examine vowel and consonant production accuracy of school-age children with mild-to-profound HL in comparison to their normal hearing peers and to examine, 3) identify the phonological processes that persist in the speech of school-age children with hearing loss (CWHL) in comparison to their peers, and 4) investigate how the speech-intelligibility of CWHL and children with normal hearing (CWNH) is rated by adult listeners with differing levels of familiarity with a child's speech characteristics.

Methods: Children with hearing loss (CWHL, N=25; mean age of identification=25.9) were compared with children with normal hearing (CWNH, N=30) with similar age, gender, linguistic, and socioeconomic backgrounds. Productions of English words were elicited in a picture-naming task using a list of 88 words, derived from three standardized speech tests. Parents (N=24), teachers (N=24), inexperienced listeners (N=24) and experienced listeners (N=24) rated children's speech intelligibility on a 6-point scale.

Results: The first study showed that CWHL produced fewer stops, fricatives, affricates, and liquids than CWNH. CWHL had acquired more sounds in onset than coda position. Most CWHL had similar vowel repertoires to CWNH. The second study showed that CWHL and CWNH had similar vowel production accuracy. CWHL had lower percentage of consonant correct than CWNH. Consonant production accuracy for CI users was better than for HA users. Children with moderate-to-severe HL were the least accurate in phonemic production. The third study revealed that there was distinctive differences between CWNH and CWHL in the amount of processes produced by younger and older CWHL. CWHL showed a similar trend of age of suppression to CWNH but at a slower rate. Final consonant deletion, weak syllable deletion, backing, and glottal replacement were present in the speech of HA users which would affect their overall speech intelligibility. The fourth study showed that parents, teachers, and experienced listeners rated speech intelligibility of CWHL better than inexperienced listeners.

Conclusions: Some children with mild to profound hearing loss had reduced phonetic repertoires compared to their peers at early school age. Children with moderate-to-severe hearing loss who are fitted with hearing aids need comprehensive assessment and intervention services. The findings indicate that it is important for clinicians to consider phonological assessment in CWHL and the use of evidence-based speech therapy for pre-school CWHL to reduce the presence of non-developmental and non-age-appropriate developmental processes in order to enhance their speech intelligibility. Finally, it is helpful in clinical contexts to consider the perceptions of parents and other listeners who are familiar with a child's speech, and the perceptions of less familiar listeners when evaluating the intelligibility of CWHL.

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List of Abbreviations

AVT = Auditory Verbal Therapy

BAHA = Bone Anchored Hearing Aid

BTE = Behind the Ear

CASALA = Auditory Verbal Therapist

AOD = Advisors on the Deaf

CWHL = Children with Hearing Loss

CWNH = Children with Normal Hearing

CI = Cochlear Implant

DEAP = Diagnostic Evaluation of Articulation and Phonology

GFTA -2 = Goldman-Fristoe Test of Articulation-2

HA = Hearing Aid

HAPP-3 = Hodson Assessment of Phonological Patterns-Third Edition

HL = Hearing Loss

NZE = New Zealand English

NZSL = New Zealand Sign Language

PCC = Percent Consonants Correct

PVC = Percent Vowels Correct

RTD = Resource Teachers of the Deaf

SLP = Speech-Language Pathologist

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The undersigned hereby certify that:

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Chapter 1: Introduction

Introduction

This PhD is a descriptive study of the speech profile of school-age children with mild-to-profound hearing loss in comparison to children with normal hearing aged 5;0-7;6 years in New Zealand. The participants are a convenience sample of children with hearing loss recruited from across the country, but primarily in the Auckland region in the North Island.

This research project was inspired by my work with school-age children with hearing loss (CWHL) and the clinical challenges that speech language pathologists (SLPs) face in daily practice. Children transit from kindergarten to school by the age of five, which is considered a huge shift in the learning environment. Based on clinical observations, it appears that, at this transition stage, parents have concerns about their child's ability to communicate with teachers and other children when the child's speech is not clear to unfamiliar listeners by school age. Hence speech intelligibility is an important consideration for CWHL. Another important reason for investigating the speech profile of school age children is that previous research has shown that there is a relationship between speech sound disorder and literacy (White-Canales & Adrienne, 2015). The overall goal of the thesis was to gain a better understanding of the speech problems of CWHL who were diagnosed with hearing loss before the newborn hearing screening (NHS) programme was implemented in New Zealand by exploring a) which sounds children with mild-to-profound HL can produce, regardless of the targeted sounds, b) the sounds that children correctly produce in comparison to the adult target, c) the types of phonological processes (developmental and non-developmental) that occur in the speech of CWHL and that affect their intelligibility, and d) how well familiar (parents and clinicians) and unfamiliar listeners understand children with various degrees of hearing loss (HL). This chapter will begin at the beginning with general information about HL and definitions. Next, the speech profile of CWHL will be discussed, along with standardized speech assessments and the small number of studies that have been conducted on school-age CWHL. At the end of the chapter the purposes, significance and nature of the research conducted for this thesis are outlined.

Children with Hearing Loss

Hearing loss is the inability to hear sounds partially or totally in one or two ears, usually with an auditory threshold of greater than 15 dB HL at any frequency (Thorne et al., 2008; Tye- Murray, 2009), although threshold definitions vary. Stach and Ramachandran (2014) noted that “A hearing disorder results from a disruption in function of structures that transit an acoustic signal from the outer ear to the point of perception in the brain.” (p. 8). In New Zealand (NZ), HL has been categorised based on degree of HL as follows: slight (15–25 dB HL), mild (26–40 dB HL), moderate (41–55 dB HL), moderately severe (56–70 dB HL), severe (71–90 dB HL), and profound (91 dB HL and above) (Northern & Downs, 2002; Thorne et al., 2008). Northern and Downs (2002) explained that any degree of HL may affect a child’s speech intelligibility and learning ability. Researchers have categorised CWHL into two groups: 1) *hard of hearing children* who have mild-to-severe HL; and 2) *deaf children* who have profound HL. Hearing loss may occur prelingually in which the child has HL before acquiring spoken language skills or postlingually in which the child has HL after acquiring spoken language.

It is important to consider the impact of different degrees of HL as the literature indicates an association between hearing severity and children’s speech outcomes. The effects of HL on the speech of school-age children with mild-to-profound HL are discussed in chapters 2, 3, 4, and 5.

Prevalence of Hearing Loss

The World Health Organization (WHO) considers HL to be associated with significant disability. An estimated 538 million people globally have a HL >35 decibels hearing level (dB HL) (Olusanya, Neumann, & Saunders, 2014; Stevens et al., 2011). There is no consensus regarding the prevalence or incidence of HL around the world because of various degree of HL, age of identification, and the geographical areas that are involved in different surveys (Kumar et al., 2008). For example, in the United States of America (USA), the overall estimates of HL are between 1 and 6 per 1,000 newborns (Cunningham & Cox, 2003). In Australia, the prevalence is estimated to be 1.2 per 1,000 newborns (Kumar et al., 2008). A pilot study by Bailey, Bower, Krishnaswamy, and Coates (2002) conducted in Western Australia and found that 0.68/1000 of children screened at birth had bilateral permanent hearing loss (> 35 dB HL in the better ear). In the United Kingdom (UK), Fortnum, Summerfield, Marshall, Davis, and Bamford (2001) conducted a retrospective study of all children born in the UK from 1980 to 1995, and found 1) 17,160 individual children had permanent bilateral hearing loss > 40 dB HL; 2) there was a prevalence of 0.91/1000 for 3-year-old children, and 1.65/1000 for children aged 9-16 years. Prevalence in these studies would be higher if children with mild and unilateral HL were included. It is estimated that the prevalence of HL in UK will increase based on Royal National Institute for Deaf People (RNID), primarily due to population ageing, with an estimated 15.6 million people with HL in the UK by 2035. A report regarding the economic impact and cost of HL in Australia (Vicdeaf, 2006) estimated that 11.4% of the population had mild HL, 4.0% had moderate HL, and 2.0% had severe HL. They also estimated that the prevalence of HL in Australian children younger than 15 years would increase to one in four Australians by 2050 because of exposure to noise from electronic devices (Vicdeaf, 2006).

In New Zealand (NZ), there is no comprehensive study of the prevalence of HL in children. Information provided in the latest Deafness Notification Database report (Digby, Purdy, & Kelly, 2015) shows that New Zealand's Universal Newborn Hearing Screening (UNHS) programme started in 2007 but the largest Auckland-based District Health Boards

(Counties Manukau, Waitemata and Auckland) started hearing screening later in 2010. Digby et al. (2015) reported that the prevalence of bilateral and unilateral HL of the overall NZ population is not known. Based on available data, Digby and colleagues (2015) estimated that there should be 90 diagnoses of HL per 62,000 newborns in NZ per year. Exeter, Wu, Lee, and Searchfield (2015) recently published the first study in NZ to use population projections to estimate the burden of HL and they estimated that there were 330,269 people aged ≥14 years with HL, which would increase to 449,453 in 2061. Overall little is known about the prevalence of various degrees of HL and the consequences for children's communication skills in New Zealand.

Type of Hearing loss

There are three types of HL, depending on the site of damage in auditory system: conductive, sensorineural, and mixed or a combination of these (Sataloff & Sataloff, 2005; Tye-Murray, 2009) . A conductive HL occurs when there is an obstruction of sound transmission via the external and middle ear. Conductive HL can be caused by a congenital obstruction (microtia or atresia), ear drum perforation, otitis media in the middle ear, damage to the middle ear structures such as ossicular chain fixation, and cerumen in the ear canal. It is often curable with medical treatment or surgical procedures but if medical intervention does not work or is not appropriate, children with conductive HL will benefit from hearing aids (Stach & Ramachandran, 2014). Sensorineural HL is permanent and results from a disturbance in the inner ear, the auditory nerve, or both. It is not usually correctable medically and might be caused by ototoxic drugs, infection (e.g., meningitis), genetic factors, noise damage or ageing (Roland & Shoup, 2004). Finally, mixed HL occurs when a person has both conductive and sensorineural HL (Sataloff & Sataloff, 2005; Tye-Murray, 2009). Causes of HL in children were reported in Harrison and Roush (1996) as 49.6% unknown. Known factors such as heredity (15%), meningitis (6.7%), prematurity (3.8%), perinatal trauma

(3.8%), and maternal rubella (0.3%) together accounted for 29.6% of the reported causes of HL. For the NZ population, Digby, Purdy, and Kelly (2014) stated in the latest report from the Deafness Notification Database that 85% of children had no known cause at the time of HL detection due to newborn hearing screening which has resulted in earlier identification and less confirmation of cause via genetic testing at the time the HL was reported. Only 15% of notifications had known causes as follows: 11 cases had acquired HL (e.g. due to trauma or infection), one had a non-syndromic genetic cause, six had syndromic causes, two had other causes, and eight were not listed. It is worth mentioning that HL with any cause can have negative effect on children's communication skills.

Hearing technology: Hearing Aids and Cochlear Implants

Audiologists implement a comprehensive diagnostic evaluation on children to determine the degree of HL and recommend appropriate listening devices (one or two hearing devices). Digital hearing aids (HAs) and cochlear implants (CI-s) are common hearing technology devices that have been used in order to make speech sounds more audible, restore a range of loudness experience, and allow the child's brain to access auditory stimulation.

Hearing aids

A hearing aid is a communication device which consists of a microphone, an amplifier and a loudspeaker (receiver). The microphone collects acoustic signals from the environment and converts them into an electrical signal. The signal then passes into the (digital) amplifier which increases the intensity of the electrical signal before transmitting the signal to the loudspeaker to be delivered acoustically to the ear. The loudspeaker converts electrical signals into acoustic signals which are delivered through an ear mould or tubing in a conventional hearing aid or via bone conduction device (Dillon, 2012; Tye-Murray, 2009). There are different styles of HAs such as completely-in-the-canal, in-the-canal, behind-the-ear aid (BTE), and in-the-ear (Husket, 2004; Tye-Murray, 2009) . Most of the children with mild-to-severe HL in the current study were fitted with BTE (except for one child who was fitted with a soft-band bone anchored hearing aid (BAHA).

Cochlear implants

A cochlear implant (CI) is a widely used hearing technology for children and adults with severe-to-profound hearing loss who receive insufficient sound through hearing aids. The CI is an electronic hearing device that is surgically implanted in children or adults in order to compensate for damaged sensorineural areas of the cochlea by bypassing the damaged area and directly stimulating the auditory nerve. The CI consists of two pieces: internal and external. The microphone picks up sound signals from the environment and sends them to the external speech processor which analyses sounds into a code, preserving frequency, duration, and intensity cues in the input signal in a specific way depending on the speech coding program in the speech processer. The electrical coded signal from the speech processor is transmitted to an electrode array implanted in the cochlea which directly stimulates the spiral ganglion cells in the auditory nerve. The signal from the auditory nerve is transmitted to higher centres in the auditory pathway as would occur in a person with normal hearing (Clark, 2003; Skinner et al., 1994). The CI provides recipients with consistent access to speech but the signal is compromised compared to that available to children with normal hearing (CWNH). CI users receive speech sounds and other auditory signals differently from CWNH but despite this can develop very good speech perception abilities. Many children with severe-to-profound HL are now fitted with one CI in one ear and a HA on the other ear, or bilateral CIs (Litovsky et al., 2012). In the current project, CI children were either fitted with unilateral CI, or one CI and one HA on the contralateral side, or bilateral CIs.

The impact of hearing loss in children

Auditory stimulation facilitates early speech perception development in infants with normal hearing and speech perception facilitates early speech and language development (Moore, 2002). Kuhl (2004) noted that the foundation for early speech perception take a place during the first year of life for CWNH. During the first two months of life, infants will articulate non-speech sounds as their perceptual ability to discriminate phonetic contrasts develops. Many infants' perceptual ability progresses to the level of showing a preference for vowel phonemes of their mother tongue by six months of age (Kuhl, Williams, Lacerda, Stevens, & Lindblom, 1992). After that infants are able to recognize sounds and sound sequences from their native language at the age of nine months. This speech perception development will enable infants to reach a canonical babbling stage which eventually will lead to the development of first word production at approximately 12 months (Kuhl, 2004).

Tsao, Liu, and Kuhl (2004) conducted a longitudinal study of children (N=28) with normal hearing (at 6, 13, 16, & 24 months of age) and found a significant correlation between speech perception at 6 months and word production at 2 years. Therefore, pre-linguistic HL is likely to affect speech perception development and in turn early speech development. CWHL, especially those who are late-identified and late fitted with hearing devices, miss out on spoken language input and do not develop perceptual and phonological skills at the time these skills are typically acquired. They may face more challenges in developing speech production in the long term as a result of missing out on auditory input early on (Houston, Pisoni, Kirk, Ying, & Miyamoto, 2003; Moeller et al., 2010; Osberger & McGarr, 1982; Sininger, Doyle, & Moore, 1999). Early identification, appropriate audiological management, and early habilitation are essential for positive outcomes for

CWHL (Arehart & Yoshinaga-Itano, 1999; Ertmer & Goffman, 2011; Geers et al., 2002; Geers, Nicholas, Oetting, & Redmond, 2011; Geers & Nicholas, 2013).

HL may negatively affect a child's speech, language, reading, and writing development (Barry et al., 2001; Nathan, Stackhouse, Goulandris, & Snowling, 2004; Werker & Tees, 2005; Wray, Flexer, & Vaccaro, 1997), which may also impact the child's self-esteem and social/emotional development (Nicholas & Geers, 2003; Tye-Murray, 2009). The focus of this PhD is on speech, but the broader impact of HL for children is acknowledged.

Speech Assessment and Analysis

Speech outcomes are of particular interest in CWHL as they affect the ability to participate in learning and social activities which typically rely on children having intelligible speech. This heightens the importance of applying evidence-based speech therapy approaches with CWHL. As more children with CIs and HAs enter mainstream educational settings, SLPs will need to use standardized or other speech assessments as required by education providers and funders to determine whether children qualify for services such as speech therapy. Standardized speech assessments commonly used picture naming to elicit single word production. SLPs may also assess speech using conversational or spontaneous speech samples (Bauman-Waengler, 2012; Pena-Brooks & Hedge, 2000) . A 2007 survey of SLPs using single word tests with children with speech sound disorder (SSD) showed that most SLPs in the United States use the Goldman-Fristoe Test of Articulation (GFTA) (Goldman & Fristoe, 2000; Skahan, Watson, & Lof, 2007). The GFTA-2 is easy-to-administer, efficient, and relatively inexpensive as it is combined with the KLPA (Khan & Lewis, 2002). Skahan et al. (2007) argued that single word standardized tests are not representative of the child's speech as people communicate through connected speech rather than using single words (Pena-Brooks & Hedge, 2000). Children tend to produce more errors in the connected speech than in single word tests (Morrison & Shriberg, 1992). The transcription of connected speech samples for highly unintelligible children can be difficult as the target productions might not be identified (Shriberg, Austin, Lewis, McSweeny, & Wilson, 1997). Moreover, the connected speech sample obtained from a child with unintelligible speech may be limited and not representative of what they are capable of producing because they may avoid using difficult sounds and words (Williams, 2003). An important challenge with spontaneous speech samples is that transcription is a time consuming task, and this might be not be clinically feasible for SLPs who work in school settings with demanding caseloads (Bernhardt & Holdgrafer, 2001; Pena-Brooks & Hedge, 2000; Skahan et al., 2007). These disadvantages of using connected speech samples probably account for the common reliance of SLPs on single word tests.

Standardized speech assessments that used single words provide a time efficient technique for diagnosis, production analysis and setting of speech therapy goals. Single-word standardized tests are designed to elicit a representative sample of most or all English consonants in initial, medial and final position. Vowel and cluster production are targeted in some but not all tests (Eisenberg & Hitchcock, 2010). In single-word tests the examiner knows the target words, which makes the transcription process much easier and helps in identifying the underlying phonological processes for children with highly unintelligible speech (Hodson, 2006) . In addition, standardized tests provide the SLP with: 1) normative data regarding the age of suppression of phonological processes; and 2) quantitative results which enable SLPs to decide whether a child has delayed or disordered speech. In addition, the position of the speech errors in the word helps the SLP to decide the position of the sound to target in therapy. Standardized test results may also be important in many clinical settings as they form the basis for the decisions regarding the child’s entitlement for speech therapy services (Tyler et al., 2002).

Contemporary studies indicate that standardized speech assessments do not provide SLPs with a sufficiently comprehensive evaluation and many recommend adding supplementary data such as using additional words. For example, Eisenberg & Hitchcock, (2010) examined whether the content of eleven standardized tests was sufficient to determine the child's phonetic inventory and found that none of the tests contained sufficient coverage for vowels and consonants. Interestingly, Eisenberg & Hitchcock, (2010) reported that the Diagnostic Evaluation of Articulation and Phonology (DEAP) (Dodd, Hua, Crosbie, Holm, & Ozanne, 2002, p. 494) "… included at least one phonetically controlled word for all 22 consonants in word-initial position…" while the Goldman-Fristoe Test of Articulation 2 (GFTA-2) (Goldman & Fristoe, 2000) and the Hodson Assessment of Phonological Patterns-Third Edition (HAPP-3) (Hodson, 2004) " … included a phonetically controlled word for only 14 or 15 of the word-final consonants.". Recently, Flipsen and Ogiela (2015) investigated psychometric characteristics of ten single-word tests in order to provide clinicians with better understanding of whether these tests provide sufficient information and to help SLPs decide which test to use when evaluating children's speech. Flipsen and Ogiela (2015) concluded that the DEAP test provided examiners with diagnostic accuracy data and enabled clinicians to identify children with speech sound disorder (SSD) and those with typically developing speech. In addition, Kirk and Vigeland (2015) examined whether nine single-word tests provide sufficient number of opportunities to examine phonological processes (11 common phonological processes) in children's speech and found out that none of the tests provided the examiner with four opportunities for every phonological processes. These studies indicate that available single-word tests provide clinicians with insight into consonant and vowel production and phonological processes but there is a need for a more comprehensive word list.

The speech of CWHL has previously been assessed using standardized assessments such as the DEAP, GFTA-2, and HAPP-3 (Buhler, DeThomasis, Chute, & DeCora, 2007; Ching, Leigh, & Dillon, 2013; Day, 2013; Ertmer, 2010; Fairgray, Purdy, & Smart, 2010; Flipsen, 2011) but it is not known which assessment tool would provide SLPs with the most relevant, detailed information about the type of speech errors that CWHL may have. Existing tests were primary developed to determine speech errors in children with SSD, not HL, and hence they were not designed with particular consideration of the effects of HL on speech production. The HAPP-3 and DEAP Articulation subtests both examine vowel inventory, but vowels are not included in the GFTA-2. The GFTA-2 assesses articulation of consonants in initial, medial and final positions and is the most commonly used test by SLPs (Skahan et al., 2007), particularly in USA, because it has normative data for a wide age range. The DEAP provides clinicians with information about the type of speech errors (developmental or unusual patterns) and the extent of the identified phonological delay. The HAPP-3 is used to rate speech severity and describe types of phonological patterns. As no one test covers the consonant inventory in onset and coda position, consonant accuracy in onset and coda position, and developmental and non-developmental phonological processes, the current study combined words from three published assessments tests (DEAP, GFTA-2 and HAPP-3) in order to encompass the range of effects of hearing impairment on speech. More details about the word list criteria are included in Chapter 2 and additional information regarding the phonological analysis is included in Chapter 3.

Two types of analysis have been used to describe a child's phonological system: independent and relational analysis. The child's production is considered as a 'self-contained system' in independent analysis; this approach describes the child's speech system without reference to the adult production (Dyson, 1988; Stoel-Gammon & Dunn, 1985; Williams, 2003). Independent analysis includes the phonetic inventory, and syllable and word shapes

(Gordon-Brannan & Weiss, 2007). A phonetic inventory enables clinicians to identify the sounds (phones) present in a child's repertoire, irrespective of accuracy and identify the sounds that the child cannot produce. Chapter 2 focuses on the phonetic inventory with consonants sorted by word position and articulatory features (place, manner, and voicing) without reference to whether they are being correctly used (Bauman-Waengler, 2008; Stoel-Gammon & Dunn, 1985; Williams, 2003).

In relational analysis, the child's sound production is compared to the adult speech system. Using this approach a clinician can report percent correct production of consonants and vowels which will be discussed in Chapter 3. In relational analysis a phonological process (or phonological pattern) analysis is usually conducted, and here a clinician compares the child's speech performance, at word level or beyond, to the adult standards (Smit, 2004; Stoel-Gammon, 2015). Phonological processes are descriptions of simplifications to the adult speech system of phonemic contrasts in which a child may substitute a sound for another (e.g., velar fronting: car =/ta/), omit a sound (e.g., cluster reduction: star = /ta/), or add a sound (e.g., schwa insertion or addition: blue = /bəlu/; back = /bækə/). Phonological processes are discussed further in Chapter 4.

Speech profile of children with hearing loss

Previous studies have investigated one or two speech aspects of CWHL such as the phonetic inventory, phonemic inventory, phonological processes, and/or speech intelligibility (Chin, 2003; Flipsen & Parker, 2008; Serry & Blamey, 1999; Warner-Czyz & Davis, 2008; Warner-Czyz, Davis, & MacNeilage, 2010; Warner-Czyz, Davis, & Morrison, 2005). However, no study has examined all these aspects to establish a speech profile of school-age CWHL. In addition, no study has investigated speech problems in school-age children in NZ. In the current project independent and relational analyses were performed to establish a comprehensive speech profile of school-age children with mild-to-profound HL. Speech intelligibility was also examined as it provides information about an individual's daily communication abilities with a range of communication partners (Kent, Miolo, & Bloedel, 1994).

The current study investigated the speech profile of school age children unscreened through UNHS, because they were born prior to the initiation of screening in New Zealand. Therefore, we compared children's speech outcomes to international studies before and after UNHS. It is worth mentioning that any study conducted from 1970s till 1994 in the United States (US) would be prior to the establishment of UNHS programmes across all states in the US. The CWHL examined in this thesis present a population of children that are becoming quite rare in the US.

Phonetic inventory

Only a few studies have focused on the phonetic inventory of school-aged CWHL (Blamey, Barry, & Jacq, 2001; Chin, 2003), even though that it is known that HL is associated with late onset and/or fewer sounds in the babbling stage (Moeller, Hoover, et al., 2007a) and persistent speech errors (Flipsen & Parker, 2008).

There is a consensus in the literature that CWHL have smaller phonetic inventories than their peers in the pre-linguistic stage (Kent, Osberger, Netsell, & Hustedde, 1987; Lach, Ling, Ling, & Ship, 1970; Osberger & McGarr, 1982; Stoel-Gammon, 1988). This point has been examined by researchers such as Stoel-Gammon and Otomo (1986) who conducted a longitudinal study to explore babbling of 11 CWNH (4 to 18 months) and 11 children with moderately to profound hearing loss. The phonetic inventories of CWNH in the pre-linguistic stage tended to increase over time while they decreased or remained the same for CWHL. Stoel-Gammon (1988) followed this group of CWNH and 14 CWHL (*n*=12 severe to profound hearing loss; *n*=2 conductive hearing loss) up to 3 years of age and found similar results. Surprisingly, outcomes of one child with moderate conductive hearing loss (due to bilateral atresia) were poorer, as this child produced one bilabial and more alveolars while children with severe hearing loss produced more bilabials. This may reflect the quality of the amplification provided for this child.

The vocal development of CWHL appears to vary with degree of HL (Oller & Eilers, 1988). Children with mild hearing loss have earlier onset and increased volume of babbling than children with severe-to-profound hearing loss (Rvachew, Slawinski, Williams, & Green, 1999). Most studies have found considerable delay in the onset of canonical babble in infants with severe-to-profound hearing loss and a reduction in the ratio of babble compared to their peers with normal hearing (Davis, Morrison, Hapsburg, & Warner-Czyz, 2005; Eilers & Oller, 1994; Kent, Osberger, Netsell, & Hustedde, 1987; Moeller, Hoover, et al., 2007a; Oller & Eilers, 1988). Individual differences in the onset of canonical babbling have been reported for a few children with moderate-to-severe hearing loss; however, all were delayed in the onset of babbling in comparison to CWNH (Nathani, Oller, & Neol, 2007). In contrast, Davis, Morrison, Hapsburg, and Warner-Czyz (2005) found that a group of children with moderate-to-severe HL had comparable babbling to CWNH. These outcomes might be related to the small number of participants (N=3), and the children being early identified and well amplified (average aided PTA=26.5, 52, 51 dB). Two studies have reported single cases of non-implanted profoundly deaf children who achieved similar babbling onset to CWNH (Koopmans-van Beinum, Clement, & Dikkenberg-Pot, 2001; Wallace, Menn, & Yoshinaga - Itano, 1999). Koopmans et al. (2001) suggested that the early onset (7.5 months) of babbling in the speech of profoundly deaf child might be related to usable residual hearing, especially in the low frequency range. It is also possible that children in these studies not identified via newborn hearing screening have had progressive HL and were not always been profoundly deaf. Wallace et al. (1999) also reported that even though the child with profound hearing loss had similar babbling to CWNH, the child did not develop vocal competence later on. Moeller et al. (2007a) studied 12 early-identified (n= 9 HAs; n=3 CIs) CWHL and 21 CWNH from the age of 10 to 24 months to compare their phonetic development in pre-linguistic and early linguistic stages. A phone in the consonant and vowel inventory was judged to be present by two listeners who agreed that a particular sound was observed in "at least three times in at least two of three consecutive sessions" (p. 610). Moeller and colleagues found no significant difference in vowel accuracy between CWHL and CWNH. Both CWHL and CWNH produced voiceless sounds before voiced. Bilabials were produced more frequently in babble and at the first word stage at 22 to 24 months by both groups of children. However, CWHL produced significantly fewer fricatives and affricates and showed minimal progress in producing these sounds over time. The speech production of CWHL varied based on degree of HL. Children who were early identified and fitted with hearing devices, produce similar vowels and more stops, nasals, glides and few fricatives and affricates in comparison to CWNH .

Only a few studies have explored the phonetic inventory of school-age children with different degrees of HL. There is minimal information available regarding the phonetic inventory of school-age children with different degrees of HL who are using hearing aids (HAs) and further research is needed to address this issue. To our knowledge, no recent study has investigated the phonetic inventory of school-age children with mild-to-moderate HL. The phonetic inventory of children with severe HL has been examined as Carr (1953) compared the relative frequency of consonants and vowels in a spontaneous speech sample from 48 children with severe hearing loss aged five years to that of CWNH from Irwin's earlier study (1947). Children with severe hearing loss used vowels in a similar manner to typically developing children aged 11 to 12 months. They used front vowels [i, ɪ, e, ɛ, æ] and a central vowel [ʌ] more frequently than back vowels [ʊ, u, ɔ, ɒ, ɑ]. CWHL (aged 5 years) had a broad range of consonants characteristic of younger CWNH (9-24 months). Front sounds [p, b, m, w] and voiced consonants occurred more frequently than back and voiceless consonants. It is noted that children in the Carr (1953) and Irwin (1947) studies were significantly later identified with HL than today's population of children.

Contemporary studies have documented the progress in speech production for children fitted early with CIs (Ertmer & Goffman, 2011; Flipsen, 2011; Geers, Brenner, & Tobey, 2011; Tobey, Pancamo, Staller, Brimacornbe, & Beiter, 1991; Tye-Murray & Spencer, 1995; Warner-Czyz, Davis, & MacNeilage, 2010). Serry and Blamey (1999) investigated the phonetic inventory of nine children over 4 years of CI experience at 6 month intervals. The children were fitted with CIs at age 2;6 to 5;2 (years; months). At four years post-CI, 22 out of 24 consonants had reached the targetless criterion ("at least two recognizable tokens of a phone within a speech sample") (except [θ] and [ð]). Although in this study the children could produce 22 out of 24 consonants, only 13 could be considered phonemes as they matched the target /m, w, j, b, n, d, h, p, l, v, ʃ, f, r/; the children were still missing /t, k, ŋ, g, ʒ, θ, ʧ, z, s, ʤ, ð/. Thus, despite the use of CIs, production of some stops, fricatives, and affricates was still atypical. In another study, Chin (2003) reported phonetic inventories for all consonants (stops, fricatives, affricatives, nasals, approximants) for 12 early-identified children (age range 6.4-16.5; age range of implantation 1.4-6.1) who had used CIs for five years or more and differed in their communication mode (oral vs. total communication). Chin noted a trend for children with oral communication (*n*=6) to produce more English sounds such as alveolar fricatives, velar stops, and nasals than the total communication group (*n*=6). In summary, children who were fitted with CI had better phonetic inventory after extended use of hearing devices, however their phonetic inventory was delayed in comparison to their peers.

Previous studies were conducted to explore the phonetic inventory of CWHL; however, none of these studies considered whether some sounds would be more affected in the coda than onset position or vice versa, whether children with moderate hearing loss have similar phonetic inventories to children with mild hearing loss, and whether children who were fitted with CIs would have different or similar phonetic inventory to children with mild to severe hearing loss because CIs users with more profound hearing loss often receive a comprehensive therapy program within implant programs. There is little known about the type of sounds that children with mild to profound hearing loss are producing at school-age in comparison to their hearing peers. The current study attempts to address this gap in Chapter 2.

Phonemic inventory

A phonemic inventory is an account of the phones that the child uses contrastively in order to make distinctions between words (Eisenberg & Hitchcock, 2010; Klein, 1984; Stokes, Klee, Carson, & Carson, 2005). Two studies have examined speech accuracy in the speech of pre-school children with mild-to-severe HL (Ambrose et al., 2014; Tomblin et al., 2014) and reported that younger children with mild-to-severe HL were significantly less accurate than CWNH. To our knowledge, no study has been conducted on school-age children with mild-to-severe HL. More studies have been conducted with CI users, with researchers investigating whether speech accuracy improves in the speech of profoundly deaf children after extended use of CIs, and whether early implanted children have approximated the speech accuracy of children with normal hearing (CWNH) (Faes, Gillis, & Gillis, 2015; Warner-Czyz & Davis, 2008; Warner-Czyz, Davis, & MacNeilage, 2010; Warner-Czyz, Davis, & Morrison, 2005). There is general consensus across studies that CI users gain better speech accuracy when they were implanted before the age of two, however, their speech was still delayed compared to their peers (Faes, Gillis, & Gillis, 2015; Warner-Czyz & Davis, 2008; Warner-Czyz, Davis, & MacNeilage, 2010; Warner-Czyz, Davis, & Morrison, 2005). To date, researchers have not systematically examined consonant and vowel accuracy in school-age CI and HA users in onset and coda position, nor compared consonant and vowel accuracy in the speech of HA and CI children who vary in their HL severity. The current study attempts to address this gap in Chapter 3.

Phonological processes

Phonemes are the smallest unit of sound that can affect meaning in a language. Stampe (1979, p. 1) defined a phonological process as “a mental operation that applies in speech to substitute for a class of sounds or sound sequences presenting a common difficulty to the speech capacity of the individual, an alternative class identical but lacking the difficult property”. Phonological process analysis provides clinicians with a descriptive analysis of the type of speech errors that children have and indicates whether the child’s speech production is following a typical or non-typical developmental sequence. It is essential to gain this type of information about a child’s speech in order to implement evidence based speech therapy approach, since speech therapy methods have been developed to address specific processes.

CWHL use developmental phonological processes that are similar to those used by their typically developing peers with normal hearing (Abraham, 1989; Dodd, 1976; Oller, Jensen, & Lafayette, 1978). Non-developmental phonological processes have also been observed in the speech of CWHL (Abraham, 1989; Eriks-Brophy, Gibson, & Tucker, 2013; Flipsen & Parker, 2008). Phonological processes are likely to vary across children based on varying degrees of HL, age of diagnosis, intervention program, and the amount and quality of acoustic information that CWHL gain through their HAs and/or CIs. In general, children with mild to moderately severe HL have: 1) consonant articulatory errors which particularly affect fricatives and affricates (Elfenbein, Hardin-Jones, & Davis, 1994); 2) phonological processes that persist in their speech which include substitutions, distortions, and omission of consonants (Huttunen, 2001; Moeller et al., 2010); 3) almost accurate vowel production (Moeller, Hoover, Putman, Arbataitis, Bohnenkamp, Peterson, Lewis, et al., 2007; Moeller, Hoover, et al., 2007a; Yoshinaga-Itano & Sedey, 1998); and 4) overall intelligible speech (Eisenberg, 2007; Elfenbein et al., 1994). On the contrary, the speech characteristics of children with severe to profound HL have been described as: 1) having consonant articulatory errors which affect stops, fricatives, affricates, and liquids (Hudgins & Numbers, 1942; Ling, 2002; Smith, 1975); 2) having consonant errors including cluster reduction, final consonant deletion, stopping, fronting, devoicing of stops, liquid simplification, and gliding (Abraham, 1989; Dodd, 1976; Hudgins & Numbers, 1942; Markides, 1983; Meline, 1997; Oller, Jensen, & Lafayette, 1978; Osberger & McGarr, 1982; Smith, 1975; Stoel-Gammon, 1983); 3) having vowel errors including substitutions, diphthongization, and prolongation; 4) being less intelligible especially if they were late identified and late fitted with hearing technology (Ertmer, 2011; Markides, 1970; Peng, Spencer, & Tomblin, 2004). Speech characteristics of children with severe-profound HL improve after receiving a CI. In Chapter 4, 10 studies are reviewed that have investigated phonological processes in the speech of HA and CI users since 2000. Across these reviewed studies, there is consensus that CWHL have systematic, rule-governed phonological systems which consist of developmental and non-developmental phonological processes that persist beyond the expected age (Buhler, DeThomasis, Chute, & DeCora, 2007; Chin & Pisoni, 2000; Doble, 2006; Law & So, 2006; Moeller et al., 2010; Van Lierde, Vinck, Baudonck, De Vel, & Dhooge, 2005). Surprisingly, there are few studies that have investigated phonological processes that persist in the speech of school age-children with mild-to-profound HL using different types of hearing technology in comparison to their typically developing peers. In addition, few studies have compared processes in the speech of CI and HA users. These research gaps will be discussed in Chapter 4.

Speech intelligibility

Speech outcomes of CWHL have been described at a phonemic level in terms of phonological processes, at a phonetic level in terms of articulatory proficiency, and at a perceptual level in terms of speech intelligibility (Blamey, Barry, & Jacq, 2001; Flipsen, 2011; Flipsen & Parker, 2008; Yoshinaga-Itano & Sedey, 1998). Chapter 5 focuses on speech intelligibility, defined as the degree to which a listener understands a speaker-delivered message. Speech intelligibility is important, as it provides information about an individual's daily communication abilities with a range of communication partners (Kent, Miolo, & Bloedel, 1994). A number of studies have examined speech intelligibility in CWHL, but none have examined differences in intelligibility ratings between parents, teachers, other experienced listeners and naïve listeners. This approach was taken into consideration in the current project (Chapter 5) as the perceptions of different listeners are important for CWHL who interact with a range of different people in their everyday life. Ratings of speech intelligibility of CWHL were obtained for children in early primary school, a stage where intelligible speech is highly desirable for CWHL placed in mainstream school settings. The overall goal of this research was to determine the need for ongoing speech therapy for CWHL to improve speech intelligibility through their school years, based on the perceptions of a range of listeners.

Clinically, speech intelligibility is used to measure speech therapy progress over time, examine transfer of trained sounds and structures into conversational speech, assess the effectiveness of intervention, reflect the child's capacity to become an oral communicator in various communication settings, and to determine the need for continuous services in mainstream education (Ertmer, 2011; Monsen, 1981; Schiavetti, 1992). Intelligible speech is an important goal for CWHL (Dornan, Hickson, Murdoch, Houston, & Constantinescu, 2010). Recent studies such as Fulcher, Purcell, Baker, and Munro (2012) found good speech outcomes for children receiving early intervention that included auditory-verbal therapy, however, few intervention studies report speech intelligibility outcomes. Fulcher et al. (2012) noted the importance of including such measures in future studies, however, the lack of consensus about how to measure speech intelligibility may be limiting research in this area. Speech intelligibility has been measured using item identification (recorded orthographically) and/or scaling procedures. Peng, Spencer, and Tomblin (2004) found that intelligibility measured using these two approaches was highly correlated ($r=.91$, $p<.001$) for experienced CI users aged 9-18 years. Similarly, Beltyukova, Stone, and Ellis (2008) found that item identification and intelligibility rating using magnitude estimation yielded the same ranking of speech intelligibility in children with severe-to-profound hearing loss.

Speech Intelligibility of Children with Hearing Loss

There have been historical changes in hearing screening and technology that have affected speech intelligibility outcomes for CWHL. There was great interest in speech intelligibility of CWHL from the 1960s to the 1980s when hearing instruments were less effective than they are today and before the advent of universal newborn hearing screening leading to earlier intervention. Overall speech intelligibility of children with severe to profound hearing loss was about 20% in this early period (Smith, 1975). More recent studies, from the 1990s onwards, show that early identification and intervention are associated with better speech production and speech intelligibility outcomes in profoundly deaf children (Barry et al., 2001; Ertmer, 2008; Flipsen, 2008; Flipsen & Colvard, 2006; Habib, Waltzman, Tajudeen, & Svirsky, 2010). Despite these advances, speech intelligibility deficits are still evident in CWHL, and more research is needed to understand why some CWHL continue to have unintelligible speech. Chin et al. (2003) compared speech intelligibility of CWHL (*N*=51) aged 2;8 to 10;8 (years; months), and CWNH (*N*=47) aged 2;6 to 6;9. CWHL received CIs between 1;5 and 5;10 with an average duration of device experience of 2;4 years. The mean sentence level intelligibility score judged by inexperienced (unfamiliar with the speech of CWHL) listeners for the CI group was quite low (34.5%) and varied widely (0-98%). Mean intelligibility scores of CWNH were better on average, increasing from 54% for 2 year olds to 95% for 4 year olds. Thus, speech intelligibility does improve with CI experience but factors contributing to the wide variability across children need further investigation.

Tobey et al. (2003) examined speech production in 181 CWHL aged 7;11-9;11. A regression analysis revealed that child and family factors such as smaller family size and younger age at implant, implant characteristics such as use of the SPEAK coding strategy, and auditory-oral communication mode (versus total communication) were associated with better speech production outcomes, including intelligibility. These children were older and had better overall intelligibility than those in Chin et al.'s (2003) study. All were implanted before 5;0 (average age at implant 3;5) and used multichannel CIs for 4-6 years (average 5;6 years). Recorded speech samples (imitated sentences varying in length from 3, 5, to 7 syllables) were judged by 108 inexperienced listeners who wrote down what they understood from the child's sentences. Average speech intelligibility of CWHL was 63.5% after 5;6 years of CI experience. Peng et al. (2004) reported similar results for 24 prelingually deaf children aged 9-18 years, with 7 years of CI experience. Speech intelligibility was 71.54% on average (SD 29.89) measured using an orthographic procedure (listener writes what s/he thought the child said) and 3.03 points (SD 1.01) on a 5-point rating scale. Consistent with Chin et al. (2003) and Tobey et al. (2003), Peng et al. found better speech intelligibility in children with more CI experience and who were using SPEAK. Thus, there are a number of factors contributing to speech intelligibility, but these have generally only been investigated in children with CIs.

Two older studies examined teachers' ratings of speech intelligibility in children using hearing aids. The first (Jensema, Karchmer, & Trybus, 1978) involved a large national survey in which teachers rated how much the speech of children and young people with HL aged 4-23 years (*N*=741) was intelligible to unfamiliar raters; only 34.4% were rated as intelligible or very intelligible. The majority of children who were included in Jensema, Karchmer, and Trybus (1978) were later identified based upon the timing of the establishment of UNHS across the US. Additionally, a significant amount of data came from residential schools for the deaf rather than public school programmes. The second study by Markides (1986) found that children who were early fitted with hearing aids (age 6 months) had better intelligibility than children late fitted with hearing aids (between the ages of 2 and 3 years) based on intelligibility ratings by a mainstream teacher.

Hearing Aids versus Cochlear Implants

Several authors have investigated speech intelligibility of CWHL fitted with HAs compared to CIs (Baudonck, Dhooge, & Van Lierde, 2010; Osberger, Maso, & Sam, 1993; Svirsky, Chin, Miyamoto, Sloan, & Caldwell, 2000; Van Lierde, Vinck, Baudonck, De Vel, & Dhooge, 2005). Results vary and depend on the technology at the time of the study. In later studies most profoundly deaf children have received CIs. Van Lierde et al. (2005) reported poorer speech intelligibility ratings (by SLPs listening to connected speech samples) in children with severe hearing loss using HAs (*N*=6) than those using CIs (*N*=9). HA users had more difficulties at both the phonetic and phonemic levels. In contrast, a cross-sectional study by Baudonck et al. (2010) found that speech intelligibility of 24 profoundly deaf children using CIs did not differ from that of 24 children with moderate to severe-profound hearing loss using HAs. These HA users had better hearing on average than those in Van Lierde et al.'s (2005) study suggesting that speech audibility is a key determinant of speech intelligibility. Consistent with this, Svirsky and Chin (2000) found better intelligibility in children with more residual hearing.

Speech Intelligibility Progress over Time

Only a few studies have looked prospectively at gains in speech intelligibility over time in CWHL. Understanding the typical rate of progress is important for therapy decisions, such as determining whether a child is making adequate progress with their HAs. Geers, Brenner, and Tobey (2011) followed a sample of 100+ CWHL and found wide variability in ratings of percent words understood when the children were aged 8-9 years (*M* = 69%, range 0-100%). Although there was improvement on average when they were followed through to adolescence (*M* = 84%, range 0-95%) there was still wide variability. Ertmer (2008) used an orthographic procedure to measure speech intelligibility gains in a small sample of children (*N*=6) implanted before age three. Intelligibility scores from inexperienced listeners improved over time from 28% to 62% on average during the first three years of CI use. Each child made gains, but one child plateaued at 30 months and one improved very little. There was variability in individual outcomes even when speech detection thresholds were good. All participants had good aided hearing levels with their CI of about 20-30 dB HL. Flipsen's (2008) review examined whether intelligibility of children with severe-profound hearing loss improved in conversational speech (*N*=10 studies) after using CIs in comparison to children who did not use CI. Children who were early fitted with CIs seemed to progress to intelligible speech. Some children who were late fitted with CIs improved for about 10 years post implantation. This suggests that all CWHL have the potential to continue to improve but that this will be limited in late-implanted children. More prospective longitudinal research is needed to determine the likely progress for children with a range of hearing losses and hearing instruments.

In summary, researchers are in general agreement that intelligibility improves after cochlear implantation and is better with longer usage of hearing devices. CWHL are less intelligible than CWNH, and intelligibility outcomes vary widely across children with the same degree of HL and may be influenced by hearing technology (Chin et al., 2003; Ertmer, 2008; Flipsen & Parker, 2008; Geers, Brenner, & Tobey, 2011; Peng et al., 2004; Tye-Murray & Spencer, 1995). There are still a number of gaps in the literature. For example, few studies have measured different raters' perceptions of the speech of individual CWHL and few studies have compared the speech intelligibility of HA to CI users. These are the gaps that are discussed in Chapter 5.

Overview of the thesis

To date, studies of CWHL have focused primarily on speech outcomes of children with profound hearing loss who were late or early fitted with CI rather than on the speech outcomes of school-age children with mild-to-severe hearing loss. It is important for SLP to understand the speech problems of CWHL in order to make clinical decisions and implement evidence-based practice (EBP). A SLP uses EBP when they integrates their expertise, external scientific evidence, and the client's needs and parents' perspectives to provide the client with the best possible therapy service. From a clinical point of view, clinicians face many challenges when they work with CWHL as the literature lacks a comprehensive speech profile of school-age children with mild-to-profound hearing loss that could form a foundation for understanding the kinds of sounds that a child with HL can produce (phonetic inventory), the types of sound that a child with HL can produce correctly in comparison to typical developing children (phonemic inventory), the types of phonological processes that may persist in their speech, and how much an unfamiliar listener may understand the speech of CWHL in comparison to their parents, teachers and clinicians (speech intelligibility). Another clinical challenge is that SLPs are required to assess children's speech using standardized speech assessments to determine whether the child is eligible for special educational support. Unfortunately, none of the available standardized speech assessment tests were specifically designed to assess speech errors in CWHL. This leaves clinicians to wonder whether a particular assessment will reflect the child's speech problems or whether the test would overestimate the child's speech ability.

This thesis is presented as a "thesis with publication" in accordance of the University of Auckland *Guidelines for including Publication in a Thesis.* Chapters 2, 3, 4 and 5, contain papers in preparation for submission to a peer-reviewed journal. Chapters 2, 3, and 4 have similar methodology (*N*=25 CWHL; *N*=30 CWNH) while Chapter 5 has additional participants as it includes different groups of rates (*N*=22 experienced listeners; *N*=30 inexperienced listeners) in addition to the CWNH and CWHL in order to assess speech intelligibility.

The current research is novel. This is the first study in NZ to investigate the speech profile of school-age children with mild-to-profound HL. There are some international studies that addressed different speech aspects for CWHL but there is no available literature on this topic in NZ. This study provides detailed description of the speech profile of CWHL in NZ predominantly identified prior to UNHS, which lays the foundation for future studies of CWHL post-UNHS. In addition, we established a word list (88 words) derived from three standardised, commonly used tests to examine the speech outcomes of CWHL.

The overall aim of the doctoral thesis was to provide an in-depth description of speech abilities, speech errors, speech accuracy and speech intelligibility in school-age children with mild-to-profound HL.

Objectives

The specific objectives of the study were:

1. To describe the phonetic inventory of New Zealand English (NZE) of early school-age children with a range of HL in comparison to their peers. We also wanted to know whether the phonetic inventory profile of children varies based on sound position (onset vs. coda) in the word.

2. To examine vowel and consonant production accuracy in the New Zealand English (NZE) speech of early school-age children with mild-to-profound HL in comparison to their normal hearing peers and to examine speech accuracy (in terms of percent consonants correct, PCC and percent vowels correct, PVC) in the speech of HA versus CI users to know whether they are at a similar level by school-age. We also wanted to explore the phonemic accuracy in onset and coda positions in three groups of CWHL: mild, moderate-severe, and profound hearing loss.

3. To identify the most common phonological processes that persist in the speech of school-age CWHL in comparison to their peers. This included a comparison of the phonological processes persisting in the speech of HA and CI users.

4. To examine the impact on intelligibility ratings of the characteristics of the person rating the child's speech. Intelligibility ratings of inexperienced and experienced listeners were compared in order to address the following questions:

    a) Does listener familiarity with a child affect ratings of intelligibility of CWHL and CWNH?

    b) Do intelligibility ratings differ between children using HAs and those using CIs?

    c) Are speech intelligibility ratings correlated with articulatory proficiency, as measured by the Diagnostic Evaluation of Articulation and Phonology (DEAP) (Dodd et al., 2002)?

Thesis outline

This thesis is divided into six chapters. Chapter 1 provides general information about children with HL, and the need to establish a speech profile for CWHL in NZ. Chapter 2 examines the phonetic inventory of New Zealand English (NZE) of early school-age children with a range of HL in comparison to their age and gender matched peers with normal hearing. Chapter 3 compares consonant and vowel production accuracy of children with mild-to-profound hearing loss with that of CWNH. The phonemic production accuracy of HA and CI users is compared. Consonant production accuracy in onset and coda positions in three groups of school-age CWHL (mild, moderately-severe, and profound hearing loss) is reported. The findings highlight which group of CWHL are more likely to have speech sound disorder and need ongoing therapy program. Chapter 4 identifies the phonological processes persisting in the speech of the CWHL using HAs and CIs in comparison with CWNH. The processes that would affect the speech intelligibility of HA and CI users are noted. The presence of non-developmental processes reflects an inability to master the rules governing phonology (linguistic deficit) for CWHL, which would affect their reading and writing abilities at school. These are described in Chapter 4. As CWHL have poorer phonetic inventory and lower speech accuracy than their normal hearing peers, it is expected that CWHL will be less intelligible than CWNH. Therefore, Chapter 5 investigates how the speech intelligibility of CWHL and CWNH is rated by adult listeners with differing levels of familiarity with the speech characteristics of CWHL. Chapter 6 summarises and discusses the findings of the four cross-sectional studies.

Chapter 2: Phonetic inventory of young school-age children with mild to profound hearing loss compared with their normal hearing peers

Asad, A., Purdy, S. C., Ballard, E., Fairgray, L., Bowen, C. (In preparation). Phonetic inventory of young school-age children with mild to profound hearing loss compared with their normal hearing peers.

This publication is inserted as it will be submitted for publication, with the exception of minor edits and formatting changes to maintain consistency throughout the thesis.

Abstract

Purpose: This study describes the phonetic inventory of early school-age children with hearing loss using hearing aids and cochlear implants in comparison to their peers. A second aim was to explore whether phonetic inventory differed between onset versus coda position in words.

Method: Children with hearing loss (CWHL, *N*=25) were compared with children with normal hearing (CWNH, *N*=30) with similar age, gender, linguistic, and socioeconomic backgrounds. Productions of English words were elicited in a picture-naming task using a list of 88 words, derived from three standardized speech tests. Phonetic inventories for children in two age groups (5;0-5;11, 6;0-7;5), with and without hearing loss, using different types of hearing technology (hearing aids, cochlear implants) were determined for vowels and for consonants categorized according to manner of articulation.

Results: CWHL produced fewer stops, fricatives, affricates, and liquids than CWNH in both age groups. Results were poorest for children with moderate-severe hearing loss using hearing aids. CWHL had acquired more sounds in onset than coda position. Most CWHL had similar vowel repertoires to CWNH.

Conclusions: Most of the children with mild to profound hearing loss had reduced phonetic repertoires compared to their peers of early school age and would benefit from a comprehensive speech therapy program.

Keywords: phonetic inventory, children with normal hearing, cochlear implant, speech production.

Introduction

Children with normal hearing (CWNH) go through several stages of vocal development during the first year of life. Early vocal development depends on motor and auditory perceptual experience during the pre-linguistic stage. By ten months, typically developing infants produce ‘well-formed’ consonant-vowel syllables (CVs) (Oller & Eilers, 1988). Infants develop kinesthetic sensations associated with syllable production, and hear the acoustic output which is associated with the syllable production. Speech sound development is influenced by multiple factors such as speech perception, cognition, linguistic, and motor demands (Goffman, Ertmer, & Erdle, 2002; Oller & Eilers, 1988; Stoel-Gammon, 1988; Von Hapsburg & Davis, 2006). The auditory-articulatory loop is essential for speech production development (Stoel-Gammon, 2011). The differences between children with hearing loss (CWHL) and CWNH become apparent at the canonical babbling stage. CWHL, especially those who are late-identified, miss out on spoken language input and many perceptual and phonological skills during the time when these skills are typically acquired (Houston, Pisoni, Kirk, Ying, & Miyamoto, 2003; Moeller et al., 2010).

Profiling the phonetic inventory enables speech language pathologists (SLPs) to determine the speech sounds that the child is able to produce, which are stimulable, and which are priority sounds for therapy. Studies have investigated the phonetic inventory of CWHL in the pre-linguistic stage (age 15- 36 months) and at school age (5-16 years) but few studies have looked at the phonetic inventory of 3 to 5 year olds. Previous studies showed that CWHL have smaller phonetic inventories than their peers in the pre-linguistic stage (Davis et al., 2005; Kent, Osberger, Netsell, & Hustedde, 1987; Lach, Ling, Ling, & Ship, 1970; Moeller, Hoover, et al., 2007a; Osberger & McGarr, 1982; Stoel-Gammon, 1988), but such findings are likely to depend on the severity of HL, when it was identified and the nature of the intervention.

There is an overall improvement in speech production and speech intelligibility of some profoundly deaf children after extended use of cochlear implants (CIs) (Geers, Brenner, & Tobey, 2011), however, there is minimal information available regarding the phonetic inventory of school-age children using hearing aids (HAs) rather than CIs. Despite early age of fitting with advanced signal processing, improved speech audibility, and early intervention (with the implementation of universal newborn screening) there is still evidence for speech delay in recent studies of children using HAs or CIs (Blamey, Barry, & Jacq, 2001; Ching & Dillon, 2013; Day, 2013; Ertmer, 2010; Ertmer & Goffman, 2011; Ertmer & Mellon, 2001; Flipsen & Parker, 2008; Serry & Blamey, 1999; Tobey, Geers, Brenner, Altuna, & Gabbert, 2003). Although previous studies have explored the phonetic inventory of CWHL, none have compared children with different degrees of HL or different types of hearing technology. The current study attempts to address this gap.

Phonetic Inventory Analysis

Two types of analysis have been used to describe a child’s phonological system: independent and relational analysis. The child’s production is considered as a ‘self-contained system’ in independent analysis; this approach describes the child’s speech system without reference to the adult production (Dyson, 1988; Stoel-Gammon & Dunn, 1985; Williams, 2003). In relational analysis, the child’s sound production is compared to the adult speech system. Relational analysis will be discussed in chapter 3 and 4. Independent analysis includes the phonetic inventory, and syllable and word shapes (Gordon-Brannan & Weiss, 2007). This research focuses on the phonetic inventory in which consonants are sorted by word position and articulatory features (place, manner, and voicing) without reference to their correct usage (Bauman-Waengler, 2008; Stoel-Gammon & Dunn, 1985; Williams, 2003).

Phonetic inventory analysis has been widely used by SLPs to determine a child's speech sound production development, identify the child's unique speech system, identify children who have speech delay, describe changes in the child's speech over time, identify target sounds to test stimulability (Powell & Miccio, 1996), and select treatment goals (Gierut, 2005). In this type of analysis the clinician describes the child's speech system without reference to the adult production (Dyson, 1988; Stoel-Gammon & Dunn, 1985; Williams, 2003). In a national survey of speech assessments, Skahan and colleagues (2007) found that 36.2% of SLPs reported using phonetic inventory analysis 'always', and 45.7% SLPs using phonetic analysis 'sometimes' to 'infrequently' for children with speech sound disorder (SSD). Phonetic analysis is more commonly used for consonants than vowels (Eisenberg & Hitchcock, 2010).

Phonetic inventory outcomes vary across the literature according to subject characteristics, speech sample criteria, and data analysis (transcription versus acoustic features). The phonetic inventory of school-age CWNH is typically assessed using single word tests rather than connected speech samples. Smit et al. (1990) used a single word test to provide normative data for speech sound acquisition of children aged 3-9 years. Dodd, Holm, Hua, and Crosbie (2003) determined the children's phonetic inventory using a picture-naming task and included speech sounds produced either spontaneously or in imitation in the phonetic inventory. Dodd et al. (2003) defined the phonetic inventory of CWNH as containing the sounds produced in 90% of children within the age band (*N*=684, aged 4;0 to 6;11). CWNH acquired all stops, nasals, fricatives, affricates, and glides by the age of 5;0-5;11 (except /ɹ/ which was acquired by age 6;0-6;5, and /θ/ and /ð/ by age ≥7;0).

Phonetic Inventory of Children with Hearing Loss (CWHL)

Only a few studies have explored the phonetic inventory of school-age children with different degrees of HL. Most of the reviewed studies in this section were conducted pre-UNHS and children were late identified as compared to studies conducted in early 2000s. Carr (1953) compared the relative frequency of consonants and vowels in a spontaneous speech sample from 48 late-identified children with severe hearing loss aged five years to that of CWNH from Irwin's earlier study (1947). Children with severe hearing loss used vowels in a similar manner to typically developing children aged 11 to 12 months. They used front vowels [i, ɪ, e, ɛ, æ] and a central vowel [ʌ] more frequently than back vowels [ʊ, u, ɔ, ɒ, ɑ]. CWHL (aged 5 years) had a broad range of consonants characteristic of younger CWNH (9-24 months). Front sounds [p, b, m, w] and voiced consonants occurred more frequently than back and voiceless consonants. Two sounds were absent from the CWHL's speech [z, ŋ] and six sounds [g, ʃ, ʒ, θ, ð, r] were less frequent than 1%, however, three of these sounds, /θ, ð, r/, were still within the norms for typically developing children (Dodd, Holm, Hua & Crosbie, 2003). West and Weber (1973) reported the phonetic inventory based on "non-comparative utterances" (sounds that could not be compared to Standard English) of a late-identified 4-year-old girl with moderately-severe bilateral hearing loss who received HAs and intervention at age 3 years. Her connected speech sample included: 1) voiced and voiceless fricatives [f, v], and the semivowel [w] most frequently; 2) stops and nasals [p, b, t, d, ʔ, f, v, m, n] several times; 3) palatal affricative [ʧ] a few times; 4) lingual fricatives [ð, z, ʃ] once or twice; 5) vowels similar to CWNH. Thus, the speech of this 4-5 year old CWHL who have had a period of auditory deprivation and/or older hearing technology (e.g. Carr, 1953) resembled that of younger CWNH. More recent research has focused on the phonetic inventory of children with severe to profound HL using CIs rather than mild to moderate hearing loss.

Contemporary studies have documented the progress in speech production for children fitted with CIs. Thus, cochlear implant studies have reported significant variation in the speech outcomes of CWHL. (Ertmer & Goffman, 2011; Flipsen, 2011; Geers, Brenner, & Tobey, 2011; Tobey, Pancamo, Staller, Brimacornbe, & Beiter, 1991; Warner-Czyz, Davis, & MacNeilage, 2010). Serry and Blamey (1999) investigated the phonetic inventory of nine children over 4 years of CI experience at 6 month intervals. The children were fitted with CIs at age 2;6 to 5;2 (years;months). Specific criteria were used to determine if a sound was within a child's phonetic inventory. This was based on targetless ("at least two recognizable tokens of a phone within a speech sample") and target ("counts only phones in intelligible words") criteria. They required "at least two correct tokens of the phone and at least 50% of all attempts at the phone to be correctly produced" (Serry & Blamey, 1999, pp. 142-143). At four years post-CI, 22 out of 24 consonants had reached the targetless criterion (except [θ] and [ð]). Although in this study the children could produce 22 out of 24 consonants, only 13 could be considered phonemes as they matched the target /m, w, j, b, n, d, h, p, l, v, ʃ, f, r/; they were still missing /t, k, ŋ, g, ʒ, θ, ʧ, z, s, ʤ, ð/. Thus, despite the use of CIs, production of some stops, fricatives, and affricates was still atypical. As the audibility of high frequency speech sounds is likely to be better with a CI than with a HA for greater degrees of HL, the production of consonants with high frequency energy such as fricatives should improve with CI experience (Blamey, Barry, & Jacq, 2001; Geers, Moog, Biedenstein, Brenner, & Hayes, 2009; Geers, Uchanski, et al., 2002). More recent studies show that children with CIs followed through school continue to have speech errors for fricatives and affricates (Blamey, Barry, & Jacq, 2001; Serry & Blamey, 1999; Tomblin, Peng, Spencer, & Lu, 2008). Blamey et al. (2001) found a plateau in speech performance 5-6 years after implantation for the nine children who were reported on in Serry and Blamey's earlier (1999) study. Eight targeted phones /ɔɪ, ʊə, t, ʒ, θ, ʧ, z, s/ still failed to attain a 50%

correct criterion in five or more of the children. Thus, audibility alone may be insufficient for ensuring speech sound acquisition in CWHL, suggesting that targeted speech therapy may still be needed.

Chin (2002) examined the stops inventory of 12 early-identified children (age range at onset of deafness 0.0-2.1 years; age range 6.4-16.5 years) who had used CIs for five years or more and differed in their communication mode (oral vs. total communication). The children varied in their speech production, with some having English stops [p, b, t, d, k, g] and others having additional non-English stops [ʔ, ʔʰ, q]. They all showed a tendency to avoid producing final voiced stops by devoicing the target sound or deleting it. The phonetic inventory was elicited using a picture-naming task (107 words) that included all English consonants in initial, medial, and final position. A sound was considered present if the child produced it at least twice regardless of the target sound. Chin did not indicate whether the sound was produced twice in the same position. A year later, Chin (2003) reported phonetic inventories for all consonants (stops, fricatives, affricatives, nasals, approximants) for the children from the 2002 study. Chin noted a trend for children with oral communication (n=6) to produce more English sounds such as alveolar fricatives, velar stops, and nasals than the total communication group (n=6). The speech of the total communication group included non-English sounds such as uvular stops more often than the oral communication group.

CWNH acquire all vowels by the age of approximately 3 years (Selby, Robb, & Gilbert, 2000; Stoel-Gammon & Herrington, 1990) but CWHL are not able to produce all English vowels until age 5 years (Yoshinaga-Itano & Sedey, 1998), indicating a significant delay in vowel acquisition. Although research has shown that vowel acquisition is delayed in the speech of late-identified CWHL, there has been little research in this area (Carr, 1953; West & Weber, 1973; Yoshinaga-Itano & Sedey, 1998; Yoshinaga-Itano, Stredler-Brown, & Jancosek, 1992). Early-identified children with CIs acquire vowel sounds similarly to CWNH in the prelinguistic stage (Ertmer, 2001; Manning, Moore, Dunham, Lu, & Domico, 1992; Nelson, Yoshinaga-Itano, Rothpletz, & Sedey, 2007).

Research into acquisition of speech sounds has examined effects of syllable position within the word. CWNH produce sounds in word-initial (onset) at a younger age than word-final (coda) (Clark, 2009). The greater salience of the onset position is likely to be due to stressed syllables having higher pitch, stronger amplitude, and longer duration than unstressed syllables (Kirk & Demuth, 2006). To our knowledge there is only one study on late-identified school-age CWHL which focuses on differences in sound position (Abraham, 1989). This study found that CWHL produced consonants with greater accuracy in onset than coda position.

The Current Study

The focus of the current study is on the phonetic inventory of school-age children with hearing loss who were identified with hearing loss before the establishment of UNHS in New Zealand in comparison to their peers. Previous literature has documented the phonetic inventory of CWHL in the prelinguistic stage and the speech development over time of CWHL fitted with CIs. We wanted to explore to what degree they differ from their peers by looking specifically at which speech sounds are impacted and have not been mastered in 5 to 7 year old CWHL. The aim of the present study was to describe the phonetic inventory of New Zealand English (NZE) of early school-age children with a range of HL in comparison to their peers. We also wanted to know whether the phonetic inventory profile of children varies based on sound position (onset vs. coda) in the word. The principle research question was: How does the phonetic inventory of CWHL differ compare to that of CWNH between 5;0-7;5 years, and are there greater differences for younger than older children within this age range? Consonants were examined based on syllable position within a word and manner of articulation. The second main research question was: How does sound acquisition differ between CWHL using HAs versus those with one or more CIs?

Methodology

Participants

Children aged 5;0-7;6 with mild to profound hearing loss (*N*=25, 11 boys, 14 girls) were matched for age, gender, and socioeconomic status (SES) to 30 CWNH (11 boys, 19 girls) (Table 1). Children were recruited from schools, Auckland Parents of Deaf Children, a private audiology clinic (Dilworth Hearing), health centres, community centres, and managers of hearing habilitation programmes (Northern Cochlear Implant Programme, Kelston Deaf Education Centre, and Van Asch Deaf Education Centre). The CWHL: a) had no diagnosed impairments other than deafness, b) had typical cognition, with or without speech and language delay, c) used HA/s or CI/s, d) used spoken language rather than sign communication as their predominant mode of communication, and e) spoke New Zealand English at home (but could be bilingual). Three CWHL who were recruited were excluded as they did not meet the inclusion criteria due to other disabilities. The majority of children (76%) in both groups (CWHL, CWNH) were monolingual English speakers. The socioeconomic status (SES) of participants was determined using the Ministry of Education school decile rankings which are based on five weighted demographic variables (income, occupation, household crowding, education, income support) from census data (Ministry of Education, 2008). Three SES ranges were used: low (deciles 1-3), middle (deciles 4-7), and high (deciles 8-10). SES status was similar across groups. Parental education level differed across mild, moderate-severe and (severe-profound) CI groups of children. A large proportion (75%) of parents of CI children had a Bachelors' degree or postgraduate qualification. Only 38-40% of parents of children with mild to severe hearing loss had university qualifications.

The control group of 30 CWNH had similar age, gender, and ethnicity to the group of CWHL. Children in the control group had no diagnosed congenital or neurological impairments, no history of speech or language disorder, normal hearing based on parental report and distortion product otoacoustic emissions (DPOAE), and English spoken at home. Control group children passed the DPOAE, measured using a Biologic Scout OAE system hearing screen at four frequencies or more (signal to noise ratio ≥ 6 dB). Bilingual children were able to participate if English was one of the languages spoken at home.

Participants' demographic characteristics for CWHL are summarized in Table 2. All but three of the CWHL were diagnosed before newborn hearing screening began in NZ. Two were diagnosed at birth and one was diagnosed in the United States and grew up in NZ. The child's most recent audiogram was obtained from the child's audiologist. An audiologist and a speech language pathologist (SLP) interpreted the audiological reports and described the degree of HL based on their unaided pure-tone average (average pure tone hearing threshold at 500, 1000, and 2000 Hz, PTA). Only two children had unilateral HL: P2 had moderately severe sensorineural and used one conventional HA; P3 had severe conductive hearing loss due to atresia and used a soft-band bone anchored hearing aid (BAHA). P1, P4, and P5 had bilateral hearing loss but wore unilateral HAs in the worse ear as they had slight or mild hearing loss in the better ear. Eight children wore bilateral HAs (4 females); six used one CI (5 females), and six had two CIs (2 females). Three bimodal device users were grouped with the other CI users for analysis. In this manuscript, HA means "uses HAs exclusively" while CI means "uses at least one CI".

Table 1. Demographic Characteristics of Children in the Two Groups

	Age		Gender		School decile				Language background	
Part.	Mean (SD)	Range	Boys	Girls	1_3 (N/%)	4_7 (N/%)	8_10 (N/%)	Median	English only	Others
CWHL	6.2 (0.7)	5.1-7.5	11	14	N=7 (28%)	N=6 (24%)	N=12 (48%)	7	19	6
CWNH	6.2 (0.6)	5.0-7.4	11	19	N=8 (27%)	N=6 (20%)	N=16 (53%)	8	23	7

Note: CWHL = children with hearing loss; CWNH = children with normal hearing

Table 2. Hearing History, Hearing Instrument for each child with hearing loss

Child	Gender	Age at testing (years)	Age of identification (months)	Unaided thresholds R ear	Unaided thresholds L ear	Sensory aid	Age of first HA fitting (months)	Age of first CI fitting (months)
P1	M	5.3	2	97	27	R: BAHA	24	_
P2	F	5.7	68	5	63	L: HA	67	_
P3	M	5.5	1	10	72	L: BAHA	65	_
P4	F	6.8	66	52	18	R: HA	75	_
P5	F	6.3	54	19	33	L: HA*	72	_
P6	F	6.3	18	55	47	Bilat HA	18	_
P7	M	5.5	30	65	60	Bilat HA	42	_
P8	M	5.5	30	62	63	Bilat HA	42	_
P9	M	7.5	41	87	83	Bilat HA	43	_

P10	F	6.8	36	55	53	Bilat HA	48	_
P11	F	5.2	8	75	70	Bilat HA	10	_
P12	F	7.1	48	58	60	Bilat HA	60	_
P13	M	5.9	48	32	28	Bilat HA	54	_
P14	F	6.8	24	100	93	R: CI	27	42
P15	F	6.6	25	92	93	R:HA; L: CI	24	54
P16	M	6.9	35	107	108	Bilat CI	_	36
P17	M	5.8	16	100	100	Bilat CI	17	21
P18	M	6.1	17	100	100	Bilat CI	17	20
P19	M	6.8	1	100	100	Bilat CI	4	23
P20	F	7.3	0	100	100	R: CI	3	12
P21	F	5.6	18	83	115	R:HA; L: CI	18	24
P22	F	6.8	7	105	105	R: CI; L:HA	12	30
P23	M	6.2	24	106	90	R: CI	20	48
P24	F	5.2	16	77	87	Bilat CI	16	20
P25	F	5.1	14	100	100	Bilat CI	14	22
Mean (SD)			**25.9 19.7**	**73.7 31.3**	**74.7 28.4**		**33.0 22.7**	**29.3 12.9**

Note. N = number; CI = cochlear implant; HA = hearing aid; NZSL = New Zealand sign language. L= left; R= right; Soft-band bone anchored hearing aid (BAHA); *Bone conduction unilateral hearing aid

Subgroups of hearing aid and implant users.

The CWHL were a heterogeneous group and hence were divided into three sub-groups: mild (PTA = 25-40 dB HL) and moderate to severe (PTA 41-90 dB HL) hearing loss fitted with one or two HAs and severe-profound fitted with one or two CIs. Demographic characteristics of HA and CI users are summarized in Table 3. Children with mild HL were late identified with HL and received less therapy services in comparison to the other CWHL. The 12 children with one or two CIs had a minimum of 25 months of CI use.

Type of therapy services.

Parents reported the therapy service that the children received. For HA users (*n*=13), 54% received services from an Advisor on Deaf Children (AODC), 23% received services from SLPs and AODCs but 23% did not receive services from any specialists. All CI (*n*=12) users received services from a multidisciplinary team that included early childhood teachers as well as SLPs, AODCs, Auditory Verbal Therapists (AVTs), and Resource Teachers of the Deaf (RT).

Procedures

Establishing a minimum word list to comprehensively assess speech of CWHL.

Because no one test is able to cover all aspects of our current investigation we combined words from three published assessments to cover syllable position, range of consonants and vowels. Speech of CWHL has previously been assessed using standardized assessments such as the Diagnostic Evaluation of Articulation and Phonology (DEAP) (Dodd et al., 2002), the Hodson Assessment of Phonological Patterns-Third Edition (HAPP-3) (Hodson, 2004), and the Goldman-Fristoe Test of Articulation 2 (GFTA-2) (Goldman & Fristoe, 2000). These tests were developed to determine speech errors in children with speech sound disorder and not to assess the speech of CWHL. The HAPP-3 and DEAP

Articulation subtest both examine vowel inventory, but vowels are not included in the GFTA-2. The GFTA-2 assesses articulation of consonants in initial, medial and final positions and is the most common used test by SLPs (Skahan et al., 2007) because it has normative data for a wide age range. The DEAP provides clinicians with information about the type of speech errors (developmental or unusual patterns) and the extent of the identified phonological delay. The HAPP-3 is used to rate speech severity and describe types of phonological patterns.

Using one standardized test does not provide SLPs with sufficient coverage for vowels and consonants of the child's speech in order to establish a phonetic and phonology profile (Eisenberg & Hitchcock, 2010; Kirk & Vigeland, 2015) and thus there is a need for a comprehensive word list. A subset of 88 words from the DEAP, HAPP-3, and GFTA-2 (Table 4) was developed that would comprehensively identify the speech difficulties of CWHL. The word list allowed more opportunities for children to produce consonants and vowels (including diphthongs) sounds in initial and coda position with a criterion of at least two productions, and used familiar words from well-established tests that were not too difficult for children to produce. The final word list included 14 words from DEAP Articulation, 47 words from DEAP phonology, 7 words from DEAP Consistency, 16 words from the HAPP-3, and 4 words from the GFTA-2. The word list consisted of 63 monosyllabic words, 19 disyllabic words, and 6 multisyllabic words.

Table 3. Demographic Information for Children with Hearing Loss Including Hearing History, Hearing Instrument Use, and Duration of Services for CI and HA Groups

	Cochlear Implant Group	Hearing Aid Group	
Characteristic		Mild HL (PTA=25-40 dB HL)	Moderate-to-Severe (PTA= 41-90 dB HL)
Children, Number	12 (6 bilateral)	4 (2 unilateral HL)	9
Males, Females	5 M; 7 F	1 M; 3 F	5 M; 4 F
Mean age at assessment (SD), [range], month	75 (8.8) [61-88]	74.3 (6.1) [68-82]	73.1 (10.3) [64-90]
Mean age at identification (SD), [range], month	16 (10.1) [0-35]	59.0 (9.6) [48-68]	23.7 (17.4) [0-48]
Unaided Pure-tone average (dB HL) for R and L ears (SD) [range]	98.4 (6.4) [92.5-105]	31.3 (4.1) [26-35]	61.1 (12.86) [41-85]
Mean age at HA fitting (SD), [range], month	14.4 (8.4) [3-27]	67.0 (9.3) [54-75]	39.1 (18.5) [10-60]
Mean age at CI activation (SD), [range], month	29.4 (12.64) [12-54]	_	_
Mean duration of HA use (SD), [range], month	12 (9.7) [4-29]	7.3 (6.9) [1-17]	33.6 (17.7) [1-57]
Mean duration of CI use (SD), [range], month	45.5 (11.7) [25-64]	_	_
Mean duration of HA and CI (SD), [range], month	57.5 (10.5) [53-78]	_	_
Communication method	Oral	Oral	7 Oral , 2 Oral & NZSL
Mean age at receiving therapy services, (SD), [range], month	23.7 (9.4) [6-42]	39.0 (17.4) [30-48]	30.1 (17.4) [10-60]
Mean duration of services,(SD), [range], month	49.8 (9.8) [32-70]	18.0 (26.5) [0-71]	30.0 (13.6) [0-50]

Note. n = number; M= male; F= female; CI = cochlear implant; HA = hearing aid; R=right; L= left; HL = Hearing loss; PTA= pure-tone average; NZSL = New Zealand sign language.

Table 4. Word List used to determine the Children's Phonetic Inventory

No.	Target	Test	No.	Target	Test	No.	Target	Test	No.	Target	Test
1	bird	DA	23	teeth	DP	45	ˈfeather	DP	67	witch	DC
2	door	DA	24	watch	DP	46	ˈmonkey	DP	68	dinosaur	DC
3	car	DA	25	ˈorange	DP	47	ˈtoothbrush	DP	69	flower	H3
4	girl	DA	26	school	DP	48	ˈapple	DP	70	fork	H3
5	moon	DA	27	crab	DP	49	knife	DP	71	glove	H3
6	fish	DA	28	ˈbiscuits	DP	50	van	DP	72	gum	H3
7	thumb	DA	29	thank you	DP	51	ear	DP	73	page	H3
8	sock	DA	30	ˈhelicopter	DP	52	this	DP	74	plane	H3
9	chair	DA	31	egg	DP	53	ˈscissors	DP	75	slide	H3
10	jam	DA	32	splash	DP	54	ˈlighthouse	DP	76	smoke	H3
11	ring	DA	33	square	DP	55	ˈzebra	DP	77	star	H3
12	house	DA	34	pig	DP	56	ˈkitchen	DP	78	string	H3
13	foot	DA	35	queen	DP	57	ˈsausage	DP	79	vase	H3
14	ˈtelevision	DA	36	three	DP	58	ˈtiger	DP	80	zip	H3
15	ˈelephant	DP	37	frog	DP	59	ˈrabbit	DP	81	ˈcrayons	H3
16	umˈbrella	DP	38	ˈyellow	DP	60	book	DP	82	green	H3
17	train	DP	39	ˈstrawberry	DP	61	boy	DP	83	nose	H3
18	swing	DP	40	ˈspider	DP	62	shark	DC	84	mouth	H3
19	bread	DP	41	web	DP	63	boat	DC	85	cup	GF2
20	duck	DP	42	sheep	DP	64	jump	DC	86	drum	GF2
21	giˈraffe	DP	43	snake	DP	65	bridge	DC	87	blue	GF2
22	five	DP	44	pram	DP	66	chips	DC	88	clown	GF2

Note. Words are from: a) DEAP Articulation (DA) (14 words), b) DEAP Phonology (DP) (47 words), c) DEAP Consistency (DC) (7 words), d) HAPP-3 (H3) (16 words), and e) GFTA-2 (GF2) (4 words) tests.
(ˈ) stress position for multi-syllabic words

A child was credited with producing a consonant or vowel if the speech sound was produced spontaneously or in imitation two or more times in the same position in at least two different words (with the exception of /ʒ/ that appeared only once). Consonants were classified according to manner of articulation: stops, fricatives, affricates, nasals and approximants (liquids and glides) in onset and coda positions (Table 5). Vowels were identified as front, central and back vowels. The criteria for inclusion of word list used to obtain phonetic inventory as follows:

1- The word list covered the 24 English consonants in onset and coda positions. The onset sounds included singleton consonants syllable initial word initial (SIWI) and syllable initial within word (SIWW). The coda covered singleton consonants syllable final within word (SFWW) and syllable final word final (SFWF) (Grunwell, 1987). The phoneme /ʒ/ is targeted only once in the SIWW position in the HAPP-3 and DEAP Articulation tests (‘television’). The phoneme /ð/ is not targeted in the final position in any test. The phoneme /ɹ/ is not present in final position NZ English which is a non-rhotic variety of English, and hence was not counted in the analysis for the final position. Phonemes /ʒ/ and /ŋ/ are not present in initial position in English. Consonants within clusters were excluded in the current paper because of the complex co-articulatory of clusters which may influence consonants production.

2- NZ English (NZE) monophthongs /i, ɪ, e, æ, ɑ, ə, ɜ, ʌ, ʊ, u, ɔ, ɒ/ (see Appendix A, New Zealand English vowel classification system: Table 2.2 from Hay, Maclagan, & Gordon, 2008) and diphthongs /eɪ, oʊ, aɪ, aʊ, eə/ (Hay, Maclagan, & Gordon, 2008; Maclagan, 2009) were tested at least twice in two different words. The number of opportunities to produce the target monophthongs or diphthongs ranged from 2-17 and 2-7 respectively. NZE speakers merge NEAR and SQUARE and do not distinguish between the /ɪə/ and /eə/ diphthongs (Bauer, Warren, Bardsley, Kennedy, & Major, 2007; Hay et al., 2008; Hay, Warrenb, & Dragera, 2006). Thus, the target words square, chair and ear were used to assess the speech production of /eə/. One vowel was targeted once /ɔɪ/ (e.g., boy).

3- Words were excluded if children with normal hearing (CWNH) show a tendency to delete consonants (e.g. sandwich [sæmwɪʤ]) or flapping of /t/ (e.g. tomato [təmɑtoʊ], [təmɑdoʊ]) in certain contexts. These are acceptable pronunciations in NZ English.

4- Speech sound disorder often co-occurs with language impairment (Shriberg & Kwiatkowski, 1994). Words that in our clinical judgement had difficult morphology were excluded because using them might lead to underestimation of the children's phonetic inventories.

   a. Children with morphosyntactic deficits may omit past-tense (-ed). In this case, the deletion is related to morpheme deletion and it is not possible to assess sound deletion. Children may also produce the present progressive morpheme (–ing, jumping) as [ɪn] which does not represent the child's ability to produce /ŋ/. Therefore, the /ŋ/ sound/segment was targeted in nouns (e.g., swing) but not verbs (e.g., fishing, swimming, crying).

   b. Children have a tendency to acquire speech sounds in the final position in harmonic contexts (e.g. cake) (Eisenberg & Hitchcock, 2010). Thus words containing the same or similar initial and final consonants might not represent the inventory production in the child's speech. For this reason the word "yoyo" was excluded.

5- Words were included for which allophonetic variations of the same phoneme are considered correct pronunciations of the target sound (Grunwell, 1987). This criterion only applied to /t/, [t̚] in 'rabbit' in the word lists.

6- Words were included for which there were New Zealand English phonetic variations for some consonants and vowels compared to the original standardized speech assessment. Phonetic variations were judged according to NZ English norms (Bauer et al., 2007; Hay et al., 2008; Maclagan, 2009). The following words were included in the speech lists: train [tɹeɪn , ʧɹeɪn], bread [bɹed, bɹad], helicopter [helikɒptə, həlikɒptə, hælikɒptə], strawberry [ˈstɹɔbəri,ˈʃtɹɔbəri], apple [æpəl, æpɪl, æpʊ], school [skʊʷ], zebra [zebɹə, zɪbɹə], elephant [eləfənt, eləfɪnt], rabbit [ɹæbɪt, ɹæbət], swing [swɪŋ, swəŋ], and television [teləvɪʒən, teləvɪʒɪn].

There are some limitations of developing this new word list such as: 1) lack of normative data; 2) /ʒ/ (e.g., television) consonant was targeted only once; 3) /ɔɪ/ (e.g., boy) vowel was targeted only once; and 4) the list included only six multisyllabic words with three compound words (e.g., lighthouse, thank you, and toothbrush).

Test procedure and equipment.

Children were tested in a quiet room at the school, at home or in the clinic. Assessments were presented in randomized order. Prior to assessment, the purpose of assessment was explained verbally and children signed an assent form. The study was approved by the University of Auckland Human Participants Ethics Committee. Children were shown pictures (DEAP, GFTA-2) and objects/pictures (HAPP-3) and were asked to name the item. For all tests, the examiner asked the child “What is this?”. If the child could not name the target, the examiner named the target and described the picture before asking the child to name it again (e.g., delayed imitation “This is an elephant, it is an animal, what is this?”). If the child could not name the target, a forced choice was provided such as “Is this car or an elephant?” Words were selected for the forced choice with different syllable numbers – monosyllabic versus di- or tri-syllabic. One child with hearing loss could not do the task without some direct imitation prompts. A high-quality microphone (HC577L) placed 10 cm from the participant’s mouth was used to record the children’s speech, and was connected to a Dell LATITUDE laptop with Adobe Audition 5 software, M-Audio preamplifier, and Flip camera. The room noise level was checked prior to testing for each child using a sound level meter (CEL-240) and ranged from 40 to 66.5 dBC SPL (*M*=57.7, SD=6.5). Recordings were edited using Audacity (2.0.3) to remove examiner prompts prior to analysis.

Table 5. List of Phonemes in the Word List, Position, and Production Possibilities for Each of the 24 Target Consonants

Phone	Syllable initial (SIWI, SIWW) Onset	Syllable Final (SFWF, SFWW) Coda	Onset (O) word count: Words Coda (C) word count: Words	Phone	Syllable initial (SIWI, SIWW) Onset	Syllable Final (SFWF, SFWW) Coda	Onset (O) word count: Words Coda (C) word count: Words
p	3	3	O: 3: pig, apple, page C: 3: cup, sheep, helicopter	s	4	3	O: 4: scissors, sausage, sock, dinosaur C: 3: house, lighthouse, this
b	7	2	O: 7: biscuits, book, boy, rabbit, strawberry, zebra, boat C: 2: crab, web	z	3	3	O: 3: zebra, scissors, zip C: 3: scissors, nose, vase
t	5	3	O: 5: teeth, toothbrush, tiger, television, helicopter C: 3: rabbit, foot, boat	ʃ	2	3	O: 2: sheep, shark C: 3: splash, toothbrush, fish
d	4	3	O: 4: duck, spider, door, dinosaur C: 3: bread, bird, slide	ʒ	0	1	O: 0: not present in onset position in English C: 1: television
k	6	6	O: 6: kitchen, biscuits, car, helicopter, cup, monkey C: 6: book, snake, duck, sock, shark, fork	ʧ	3	2	O: 3: chair , kitchen, chips C: 2: watch, witch
g	3	3	O: 3: girl, tiger, gum C: 3: frog, egg, pig	ʤ	3	3	O: 3: giraffe, jam, jump C: 3: sausage, page, bridge
h	3	0	O: 3: helicopter, lighthouse, house C: 0: not present in coda position in English	m	3	6	O: 3: monkey, moon, mouth C: 6: pram, jam, thumb, umbrella, gum, drum
f	6	2	O :6: five, feather, elephant, fish, foot, fork C: 2: giraffe, knife	n	3	7	O: 3: knife, nose, dinosaur C: 7: van, kitchen, queen, train, moon, green, plane
v	3	2	O: 3: van, television, vase C: 2: five, glove	ŋ	0	4	O: 0: not present in onset position in English C: 4: monkey, swing, ring, string
θ	2	3	O: 2: thumb, thank you C: 3: toothbrush, teeth, mouth	l	6	3	O: 6: lighthouse, elephant, helicopter, yellow, umbrella, television C: 3: school, apple, girl
ð	2	0	O: 2: this, feather C: 0: not present in the final position in English	ɹ	6	0	O: 6: rabbit, ring, giraffe, orange, zebra, strawberry C: 0: not present in final position in NZ English
w	3	0	O: 3: watch, web, witch C: 0: not present in coda position in English	j	2	0	O: 2: yellow, crayons C: 0: not included in any test

Note. SIWI=Syllable Initial Word Initial, SIWW=Syllable Initial within Word, SFWF=Syllable Final Word Final, SFWW=Syllable Final within Word

Transcription procedure and reliability.

Transcribed productions were used to construct a phonetic inventory of consonants, vowels, and clusters for each child. Speech of CWHL and CWNH was phonetically transcribed by the first author using the International Phonetic Alphabet (IPA) system, including the extensions for describing disordered speech (Copyright 2005 by the International Phonetic Association).

The first investigator received training on transcribing the speech of NZE speakers in a post-graduate linguistic course. The first investigator also completed individual transcription training (using recorded samples) for the speech of CWHL with an experienced SLT (30 years of experience working with CWHL). The reliability of phonetic transcription was assessed for 80% of the samples from each group, with two transcribers working independently. Average inter-transcriber agreement between the first author and the experienced SLP was 96.8% (SD = 3.4) across the CWHL. Agreement was 98.0% (SD = 4.7) on average between a student transcriber and the first author for the speech of CWNH. This indicates a high degree of reliability (Shriberg & Lof, 1990).

Data Analysis

The first author established each child’s consonant and vowel inventory in the onset and coda position. The first author counted consonant and vowels sounds produced by the child regardless of whether the produced sound met the correct target. For example, if the child produced the word car as /ta/, then production of /t/ was counted in the child’s inventory. Consonants were categorized according to manner of articulation: stops, fricatives, affricates, nasals and approximants (liquids and glides) in onset and coda position. Vowels included monophthongs and diphthongs. Results were considered separately for younger and older children aged 5;0-5;11 and 6;0-7;6 years. Younger and older age groups were considered for comparison purposes with the control group. The number of phones was calculated for each child and averages were computed to compare the phonetic inventories of CWHL and CWNH. The number of possible occurrences for each phone ranged from 2 to 9 with the exception of /ʒ/ which only occurred once. The phonetic acquisition profile for children in each group was established based on the criterion that sounds were produced two or more times in the same position in at least two different words by 90% of the children within the group (with the exception of /ʒ/). Wilcoxon matched-pairs signed-rank tests were used to compare results for the CWHL to their matched pairs in the group of CWNH.

Results

Phonetic Inventory of CWHL and CWNH: Manner of Articulation and Word Position

There were differences in the production of consonants (Figures 1-5) and vowels (Table 6) across age groups and between CWHL and CWNH. Wilcoxon matched-pairs signed-rank tests showed no group differences in the average number of stops, nasals, liquids, and glides produced in onset and coda positions for CWHL versus CWNH, for both younger and older age groups. There were significant differences between younger CWHL and CWNH, however, for fricatives and affricates in onset and coda positions (onset: z = -1.96, p = .05; coda: z = -2.10, p = .036) (Figure 2A & 2C). For older children there was a significant group difference in the average number of fricatives and affricates for onset position only (z = -2.26, p = .024) (Figure 2B & 2D). Wilcoxon matched-pairs signed-rank tests showed no differences in the average number of vowels in the younger age group, however, there was a significant difference between older CWHL and CWNH for vowel production (z = -1.55, p = .022) (Table 6).

Table 6. Average rate of vowel production for monophthongs and diphthongs for the two age groups (5;0-5;11 & 6;0-7;6) of children with hearing loss and children with normal hearing

			Age 5;0-5;11 years		Age 6;0-7;7 years	
Monophthongs		No. of opportunities	CWNH (n=10)	CWHL (n=11)	CWNH (n=20)	CWHL (n=14)
Front	i	8	8.0	7.9	8.0	7.9
	e	9	9.4	9.1	9.3	8.9
	æ	8	8.4	7.9	8.3	8.0
	ɜ	2	2.0	2.0	2.0	1.9
Central	ɪ	19	18.7	18.3	18.6	18.2
	ɑ	5	5.0	5.4	5.2	5.0
	ʌ	10	10.0	10.0	10.0	10.1
	u	4	4.0	4.1	4.0	4.2
	ʊ	3	3.0	3.1	3.0	2.6
	ə	17	16.2	16.2	16.4	16.4
Back	ɒ	7	7.0	6.8	7.0	6.7
	ɔ	4	4.0	4.1	4.0	4.1
Diphthongs	oʊ	4	4.0	4.0	4.0	4.0
	eɪ	5	5.0	4.9	5.0	4.8
	aɪ	7	7.0	6.8	7.0	7.0
	ɔɪ	1	1.0	1.0	1.0	1.0
	aʊ	5	5.0	4.8	5.0	4.9
	ɪə, eə	3	3.0	3.0	3.0	3.0

Stops.

Figure1 A-D illustrates the average number of stops produced in onset and coda position by CWHL and CWNH in each age group. Figure 1 A-B shows that CWNH and CWHL have similar productions of [p, b, t, g] in the onset position. CWHL produced more voiced alveolar [d] in the older age group and less [k] across both age groups, compared to CWNH. Figure1 C-D shows that little difference for the coda position except for [k] which was produced less by CWHL in the younger age group.

Fricatives and affricates.

Figure 2 A-D shows the average number of fricatives and affricates in onset and coda position. CWHL produced [s, z, ʧ] less often regardless of position, across age groups. Younger CWHL produced the voiceless labiodental [f] less often and the voiceless post-alveolar [ʃ] in onset position more often than CWNH. Younger CWHL produced the voiced labiodental [v] and voiced post-alveolar [ʤ] less often in both positions; these differences were reduced in the older children. Older CWHL produced [θ] and [ð] less often in the onset position but produced [θ] more often in coda position than CWNH. In summary, CWHL produced fewer fricatives and affricates than CWNH.

Nasals, liquids and glides.

Figure 3 A-D shows the average number of nasals, liquids, and glides produced in onset and coda positions. CWHL produced less [r] and more [w] in the onset position than CWNH in both age groups. Younger CWHL produced [l] less often in onset position. For the coda position, Figure 3 C-D shows that the pattern of productions is very similar across groups. NZ English speakers do not produce [r] in the coda position (Hay et al., 2008; Maclagan, 2009). Note that in NZ English [r] is non-rhotic (Hay et al., 2008).

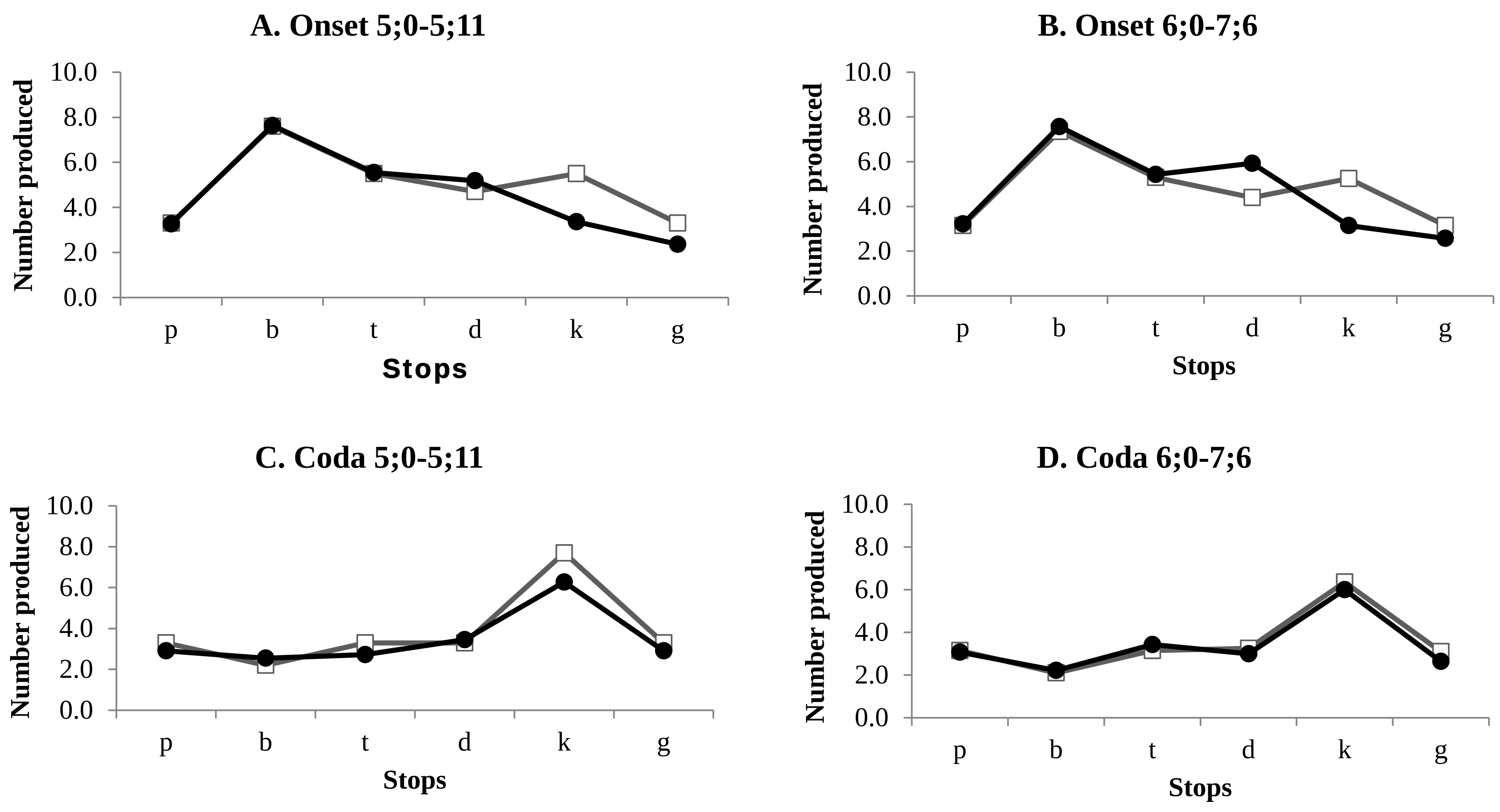

Figure 1. Average number of stops produced in onset and coda position by children with hearing loss (CWHL n=11) and children with normal hearing (CWNH n=10) aged A. & C. 5;0 to 5;11 and B. & D. 6;0-7;6 years (CWNH n=20; CWHL n=14). Black circles=CWHL

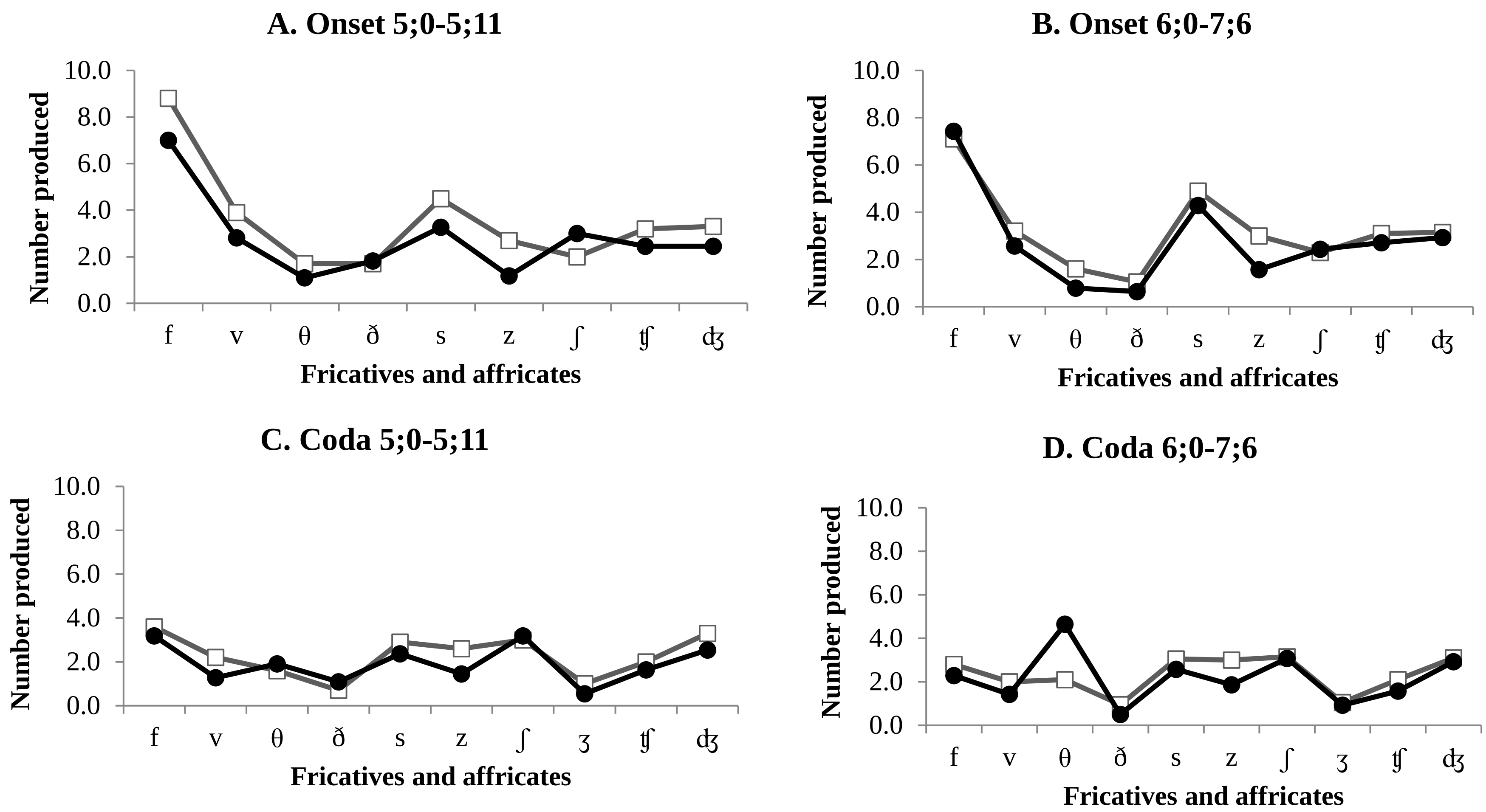

Figure 2. Average number of Fricatives and affricates produced in onset and coda position by children with hearing (CWHL n=11) and children with normal hearing (CWNH n=10) aged A. & C. 5;0 to 5;11 and B. & D. 6;0-7;6 years (CWNH n=20; CWHL n=14). Dark grey squares=CWNH.

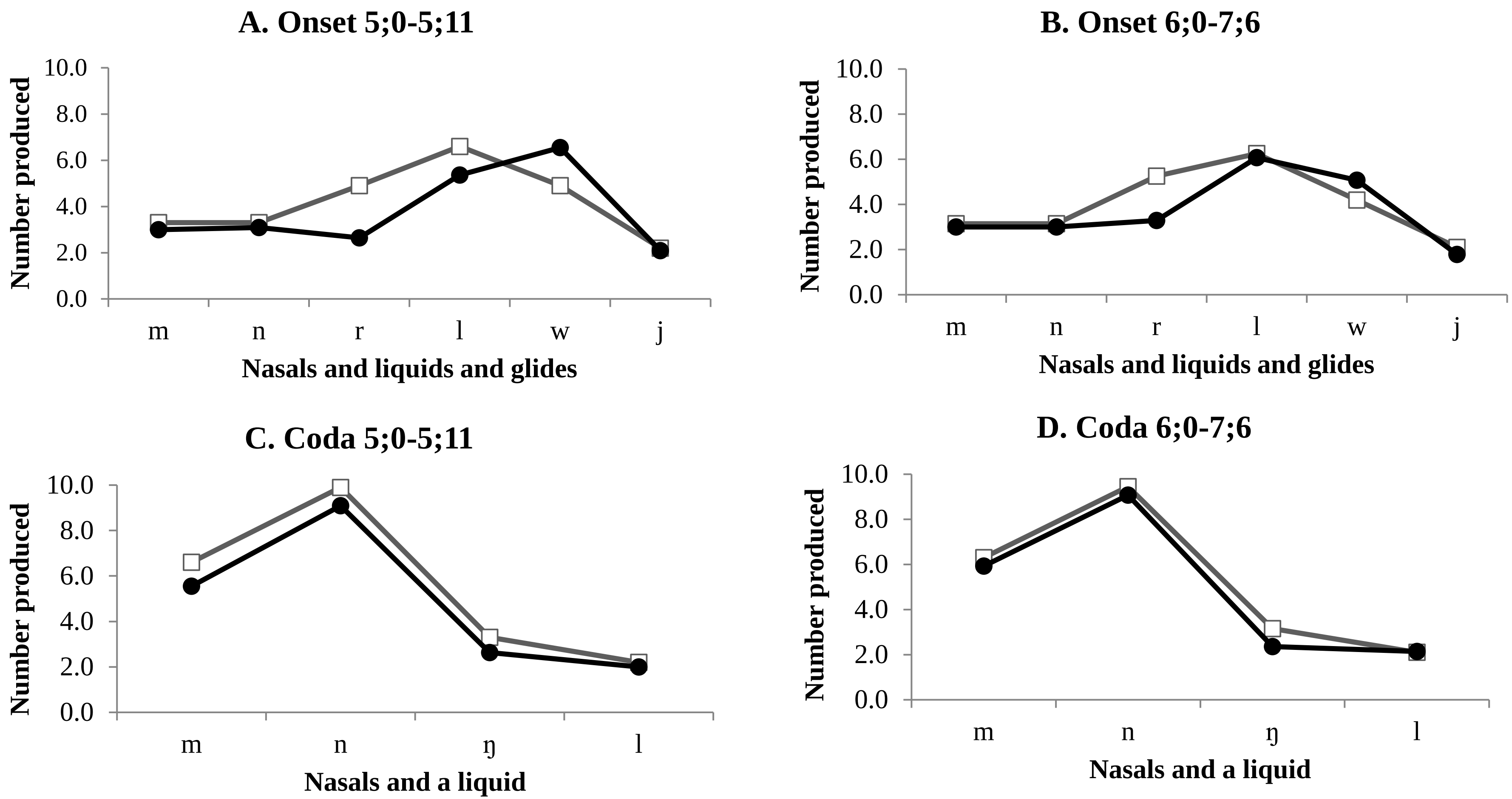

Figure 3. Average number of nasal, liquid, and glides produced in onset and coda position by children with hearing loss (CWHL n=11) and children with normal hearing (CWNH n=10) aged A. & C. 5;0 to 5;11 and B. & D. 6;0-7;6 years (CWNH n=20; CWHL n=14).

Non-ambient speech sounds.

None of the CWNH produced non-ambient sounds (i.e., sounds not present in NZ English). The non-ambient glottal stop [ʔ] occurred in coda position (almost always postvocalic) in the speech of five children with moderate-severe hearing loss (P7, P8, P9, P10, P12), and three children with profound hearing loss (P20, P21, P23). P5, who has a mild HL, produced the uvular voiceless [χ] sound for initial /k/. P5 is a bilingual speaker (English-Mandarin speaker); the presence of the uvular voiceless [χ] might be related to the interaction of these two languages (Lee, 2013; So & Leung, 2006).

Vowels

Table 6 shows that there were minimal differences in the average number of vowel productions for monophthongs and diphthongs for the younger and older CWNH. Monophthongs were categorized based on tongue position: front, central, back. For both age groups CWHL and CWNH showed some minimal differences for the central [ɪ] and back [ɒ] vowels and for two diphthongs [aɪ] and [aʊ]. Younger CWHL had slightly reduced productions of the front vowel [æ]and a diphthong [aɪ], and older CWHL had slightly reduced average productions of two vowels [e] and [ɜ] (Appendix A). Although the differences appear minimal, as noted above, the Wilcoxon signed-rank tests showed a significant difference in vowels for the older children between CWHL and CWNH. P10 is the only child who deleted the front mid long vowel [ɜ]. P21, who is a CI user, was inconsistent in producing the mid central short vowel [ɪ], as she substituted it with open central short vowel [ʌ] or open central long vowel [a] (e.g, /ræbɪt/ → /wæbat/). All CWHL tended to over-nasalise vowels when they were in front of a nasal (e.g., [ĩ]).

Phonetic Acquisition for CWHL and CWNH

A sound was counted as present in the phonetic inventory if it was produced at least twice in the same position regardless of the target sound in the word by 90% of the children in each group. Wilcoxon matched-pairs signed-rank tests showed no statistical differences between younger CWHL and CWNH for overall consonant production in onset (z = -1.46, p = .146) and coda (z = -1.51, p = .132) positions. However, there were differences for older children (onset z = -2.990, p = .003; coda z = -2.677, p = .007). Figure 4 shows the difference in the percentage of CWHL produced sounds (≤ 90%) in onset and coda position in comparison to CWNH. More than 90% of CWNH in the older age group produced every sound consistently in the onset and coda position, except [θ] and [ð] as these sounds are acquired later in typically developing children (≥7;0, Dodd et al. 2003) . A number of sounds were consistently produced by fewer than 90% of the younger CWHL in onset and coda positions. Fewer than 90% of younger CWHL produced [g, s, z, ʤ, r, j] and fewer than 90% of older CWHL produced [v, g, s, z, r, j] in the onset position. Fricatives and affricates [f, v, s, z, ʧ, ʒ, ʤ] were produced in coda position by less than 90% of the younger and older HL groups. Two stops [k, g] and one nasal [ŋ] were produced less than 90% by older CWHL in the coda position. Overall, CWHL showed a similar trend of sound acquisition to CWNH but with a speech delay.

Phonetic Acquisition for CI and HA Users

There were no statistical differences between CI group (n=12) and the combined HA users (n=13) for overall consonant production in onset (z = -1.43, p = .151) and coda (z = -1.60, p = .109) positions based on Wilcoxon matched-pairs signed-rank tests. Figure 5 shows some trends for differences in sound acquisition based on degree of HL, for the children combined across age groups, separated into three subgroups based on degree of loss. The difference between the three groups is apparent for the voiced and voiceless fricatives [ð, s, z] in the onset and coda positions, the voiceless interdental fricative [θ] in onset position, and the voiceless post alveolar affricate [ʧ] in the coda position. In general, children with mild HL had better phonetic inventories than children with moderate-severe HL and those with profound HL.

The children with mild HL had acquired all sounds except [v, θ, ð, s, z] in onset and coda position, while CI users had acquired all sounds except [g, v, θ, ð, z, r] in onset and [v, θ, ð, z, ʒ, ʧ, ŋ] in coda position. CI users are the only group of CWHL who had acquired the voiceless alveolar fricative [s] in onset and coda position. However, fewer CI users had acquired [v, ð, ʒ] in coda position. Children with moderate-severe HL were delayed in acquiring stops [k, g], fricatives [f, v, θ, ð, s, z, ʃ, ʒ], affricates [ʧ, ʤ], liquid [r], nasal [ŋ], and a glide [j] in onset and coda position compared to the other two groups. Children with moderate-severe HL and CI users were similar in their acquisition of the velar voiced stop [g] and [r] in the onset position. Overall CWHL had more challenges in acquiring sounds in the coda than the onset position. There was no difference between HA and CI users in acquiring vowels as each sound was presented at least twice in the speech of CWHL.

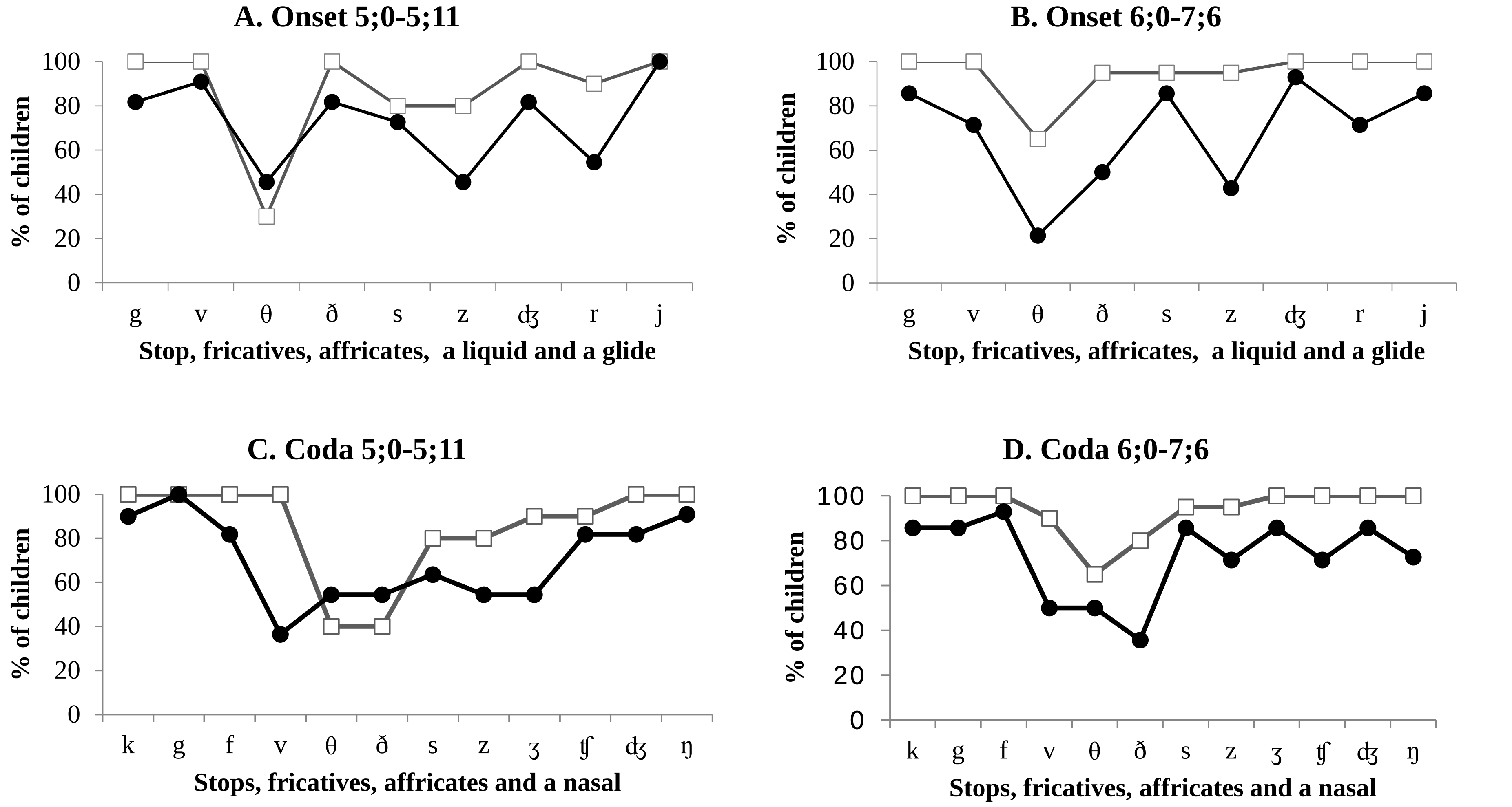

Figure 4. Percentage of children with hearing loss (CWHL n=11) who produced sounds in onset and coda position in comparison to children with normal hearing (CWNH n=10) aged A. & C. 5;0 to 5;11 and B. & D. 6;0-7;6 years (CWNH n=20; CWHL n=14).

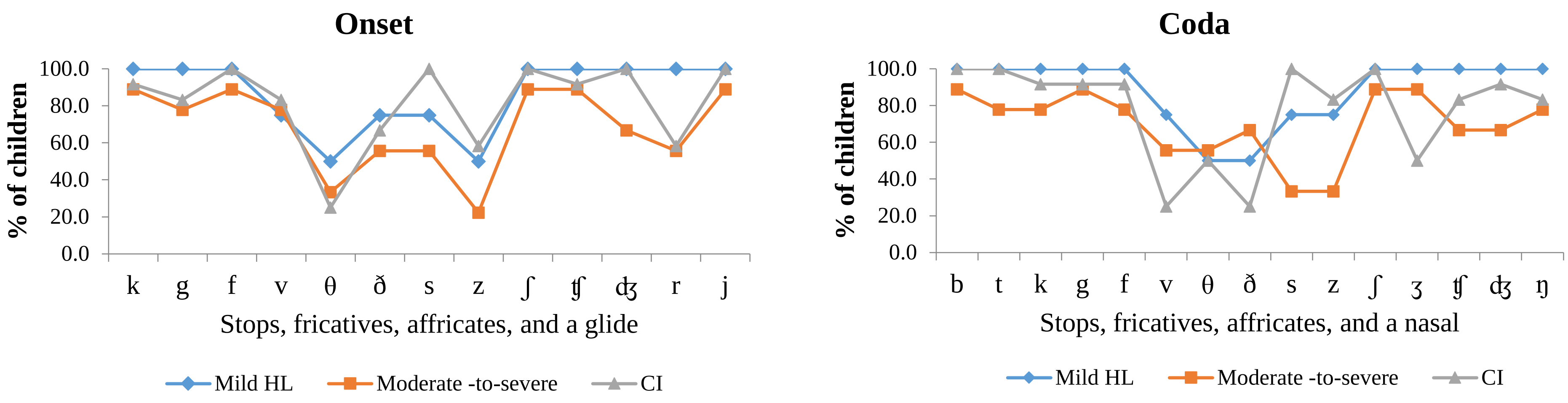

Figure 5. Phonetic acquisition of children fitted with cochlear implant (n=12) and hearing aids users for mild (n=4), moderate-severe (n=9) for some sounds produced (≤ 90%) in onset and coda. Blue = Mild HL, orange = Moderate-to-severe HL, grey = CI users.

Discussion

This study set out to 1) determine whether CWHL between 5;0-7;5 years differed in their phonetic inventory from controls, 2) explore whether phonetic inventory differed between onset versus coda position in words, and 3) determined whether sound acquisition differ between CWHL using HAs versus those with one or more CIs. In general, findings regarding manner of articulation are consistent with the literature as the CWHL had smaller phonetic inventory than CWNH. The majority of young school aged CWHL in the current study were able to produce stops, liquids, nasals, and glides in all positions but fewer children were able to produce fricatives and affricates. There were differences between CI and HA users in acquiring continuous voiceless sounds.

Phonetic Inventory of CWHL and CWNH: Manner of Articulation and Word Position

This cross-sectional study investigated the phonetic inventory and sound acquisition of CWHL aged 5;0-7;5 years in comparison to their age peers with normal hearing. CWHL were able to articulate almost all consonants and vowels but there were differences in the nature of the phonetic repertoire between CWNH and CWHL. In general, CWHL produced fewer stops, fricatives, affricates, and liquids than CWNH in both younger and older age groups.

Stops.

There was no overall difference between CWHL and CWNH in producing stops (Figure 1). Older CWHL produced more voiced alveolar [d] as they substituted the [d] sound with other voiced sounds (ð→d 'this' into 'dis', g→d 'girl' into 'dirl', ʤ→d 'gam' into 'dam'). Older and younger CWHL had more challenges in producing the voiceless velar sound [k] than its voiced cognate [g]. One CI user (P20) and two HA users (P8, P10) with moderate-to-severe hearing loss produced [k] less than two times in the same position. This is in line with previous research where it was noted that velar stops are more difficult to produce (B. Dodd, 1976).CI technology provides users with better audibility range of high frequency speech sounds than HAs for the same degree of HL (Blamey, Barry, & Jacq, 2001; Geers, Moog, Biedenstein, Brenner, & Hayes, 2009; Geers, Uchanski, et al., 2002) and hence we expected the production of velar stops to be better for CI users. This was not the case for CI user P20. Consistent with this, Chin (2002, 2003) found that velar stops were not always present in the speech of children with CIs followed for five years after implantation. Difficulty producing [k] and [g] might be related to other factors such as: 1) place of articulation being less visible than for other stops, 2) amplification may be insufficient for mid-high frequency sounds, and 3) speech therapy might not have focussed on auditory discrimination of voiced and voiceless contrasts. Tye-Murray and colleagues (1997) concluded that CI users rely on both visual and auditory feedback in acquiring speech sounds as they tend to produce more visible bilabial consonants than less visible palatals, velars, and glottal. Ertmer and Goffman (2011) also found that more visible sounds are acquired earlier in children with CIs.

Fricatives and affricates.

Previous studies have showed that CWHL have few fricatives and affricates in their phonetic repertoire and there is a delay in the developmental manner of fricatives and affricates in comparison to CWNH (Blamey, Barry, & Jacq, 2001; Moeller, Hoover, et al., 2007a; Osberger & McGarr, 1982; Serry & Blamey, 1999; Stoel-Gammon, 1985; Tobey, Pancamo, Staller, Brimacornbe, & Beiter, 1991). Figure 2 showed that younger CWHL produced fewer fricatives and affricates [s, z, θ, ð, ʧ, ʤ] than CWNH, regardless of position. Abraham (1989) also reported that 5-15 year old children with severe to profound hearing loss (*N*=13) who were fitted with HAs produced less fricatives and affricates [s, z, θ, ð, ʧ, ʤ] than stops and liquids. Similarly, Serry and Blamey (1999) found that fricatives and affricates /s, z, ʒ, θ, ð, ʧ, ʤ/ did not reach the target criteria after four years of CI experience. Even though these studies used varied methodology and differed in the age of the children and severity of HL, there is agreement that CWHL have difficulty producing most (but not all) fricatives and affricates.

The difference between CWHL and CWNH for fricatives and affricates was less in the older age group. For the older age group, there was a significant group difference in the average number of fricatives and affricates for the onset position only. Older CWHL produced [θ] and [ð] less often in the onset position but produced [θ] more often in coda position than CWNH. This finding might be influenced by the frequent substitution of the /s/ sound with [θ]. The interdental sounds [θ, ð] are considered to be within the norms as they are acquired late by typically developing children (Dodd, Holm, Hua, & Crosbie, 2003; Hay et al., 2008).

Nasals, liquids and glides.

For both age groups, CWHL and CWNH showed similar results for [m, n, j] in onset position and in coda position [m, n, ŋ, l] (Figure 3). These sounds are part of the early-8 acquired sounds in the speech of CWNH (Shriberg, 1993). Younger and older CWHL produced more [w] in the onset position because they substituted /r/ with [w] (e.g., rabbit → /wabbit/) (gliding). Dodd, Holm, Hua, & Crosbie (2003) noted that the gliding process persists in the speech of typical developing children till the age of 6 years. Gliding occurs in children speaking New Zealand English up until age 7 (Ballard, Wilson, Campbell, Purdy, & Yee, 2011; Moyle, 2005). Consistent with the current study, Abraham (1989) reported that [r] was present in 69% and [w] was always present in the initial position in the phonetic inventories of 5-15 year olds with moderate-severe HL.

Non-ambient sounds.

Children with severe to profound hearing loss in the babbling stage have a larger portion of glottal stops than CWNH (Lach, Ling, Ling, & Ship, 1970; Moeller et al., 2007a). These disappear in older CWNL but children who are CI users continue to produce glottal stops (Chin, 2002; 2003), affecting their overall speech intelligibility. In the current study, consistent with Chin, the glottal stop was present in the speech of children with moderate to profound HL in the coda position. The production of the non-ambient sound [ʔ] indicates that some CWHL in the current study have not fully acquired the linguistic system of the English language (Chin, 2002). Other individual differences for [χ] occurred in children who were bilingual speakers.

Vowels

There was a significant difference in the average number of vowels between CWHL and CWNH only for the older age group in the current study. Most vowels were present in the speech of CWHL, suggesting that they were receiving sufficient amplification of vowels and/or access to proprioceptive cues (Ling, 2002). Some of the CWHL had vowel errors, which highlights the importance of assessing vowel inventories and monitoring vowel development in the speech of CWHL. Stoel-Gammon and Herrington (1990) noted that children with speech sound disorder acquire more front vowels than back vowels. Similarly, case studies of children with speech sound disorder aged 3 to 4 years show that they substitute front vowels with other front vowels (Hargrove, 1982; Stoel-Gammon & Herrington, 1990). CWHL in the current study tended to delete and/or substitute the high front vowel /e/ vowel with [æ], which is a mid-front vowel in NZ English (Hay et al., 2008). CWHL in the current study also tended to over-nasalize vowels when they were in front of a nasal, such as in the [æ̃] vowel (e.g., thank you /θæ̃ŋkju/, van /væ̃n/). Nasalization is one of the common phonological errors in the speech of CWHL ((Flipsen & Parker, 2008; Osberger & McGarr, 1982). The current data showed that CWHL produced the back vowel /ɒ/ less often than CWNH, which agrees with Carr (1953) and Tye-Murray and Kirk (1993) who found that CWHL have a tendency to produce central and front vowels more than back vowels. For /aʊ/, a few CWHL omitted the second vowel of the diphthong (e.g., /haʊs/ → /has/, monophthongized). Diphthong reduction has been reported in the speech of children with speech disorder (Reynolds, 2002) and CI users (Tye-Murray & Kirk, 1993). Bradham and Houston (2015) noted that children may produce the first vowels in a diphthong because it is acoustically more salient. Some CWHL substituted the /aɪ/ diphthong with the mid front short vowel [æ] in which diphthongs are monophthongized. Cowie and Douglas-Cowie's review of vowel production of children with profound post-lingual deafness noted that the children tended to replace vowels within the low front cluster (/ə, ɛ, æ, a/) with "mutual interchange", with any member of the cluster being interchangeable with another (Cowie & Douglas-Cowie, 1983; Rahilly, 2013). Further research is needed to investigate monothong and diphthong development in the speech of CWHL with different degrees of HL.

Phonetic Acquisition for CWHL and CWNH

There is consensus in the literature that nasals, glides, and stops are more present in the speech of CWHL than fricatives and affricates at prelinguistic and toddler stages of phonetic acquisition (Moeller, Hoover, et al., 2007a; Osberger & McGarr, 1982; Stoel-Gammon, 1985; Tobey et al., 1991). In the current study, all sounds were present in the phonetic inventory of at least some of the CWHL, however, there were a number of sounds that fewer than 90% of the CWHL in both age groups produced: 1) voiced stop [g], voiced and voiceless fricatives [s, z, θ, ð], voiced liquid [r], and a glide [j] in the onset position; and 2) fricatives and affricates [f, v, s, z, ʧ, ʒ, ʤ] in coda position. There were individual differences in the onset position for younger and older group as fewer than 90% of the children produced: 1) voiced affricate [ʤ] in the younger group; and 2) a voiced fricative [v] in the older group.

Consistent with Abraham (1989), CWHL acquired fewer sounds in coda than onset position which might be related to the following factors: sounds in coda position are less acoustically salient and CWHL might not have sufficient audibility with their amplification and in typical development sounds are acquired later in the coda position. Three sounds [k, g, ŋ] were produced by fewer than 90% of the older group in the coda position. The sounds that the CWHL had not acquired spanned Middle-8 and Late-8 sounds (except /j/ Early-8 sounds) acquired in typical development (Shriberg, 1993). Speech delay in CWHL may reflect a number of extrinsic (e.g., late identification of HL, inconsistent hearing instrument use) and intrinsic (e.g., degree and type of HL) factors (Ling, 1978) that speech language needs to consider when planning intervention.

Phonetic Acquisition for CWHL: CI versus HA Users

Individual variability in the acquisition of speech sounds for CWHL appears to be associated with factors such as degrees of HL, mode of communication, age of hearing fitting, length of device usage, and access to early intervention. Other factors are also likely to contribute, such as the quality of the auditory environment (Geers, Uchanski, et al., 2002; Kirk et al., 2002; McDaniel & Purdy, 2013; Tobey, Geers, Sundarrajan, & Shin, 2011; Yoshinaga-Itano & Sedey, 1998) including environmental noise and distance from the listener and the nature and extent of adult-child verbal interactions (Ambrose, VanDam, & Moeller, 2011; VanDam, Ambrose, & Moeller, 2012). Even when using hearing instruments, CWHL do not have the same quality of auditory experience that CWNH gain from their environment. Children with severe-profound loss are more likely to receive CIs and participate in a comprehensive habilitation program than children with lesser degrees of HL. Children with milder hearing loss are also less likely to wear their HAs consistently (Walker et al., 2013). These factors may have played a role in the phonetic inventory of CWHL with various degrees of HL in the current study.

Children with mild HL had better phonetic inventories in onset and coda position than children with moderate-severe HL and CI users (Figure 5). Children with mild HL did not acquire five sounds [v, θ, ð, s, z] in onset and coda position (<90% of the children), indicating speech delay. Ingram, Christensen, Veach, and Webster (1980) investigated the acquisition of word-initial fricatives and affricates in the speech of typically developing children aged 2-6 years and found that four of these fricatives [v, θ, s, z] were the last sounds to be acquired based on a child producing the sound correctly 70% of the time. In the current study, CI users did not acquire six sounds [g, v, θ, ð, z, r] in onset position and seven sounds [v, θ, ð, z, ʒ, ʧ, ŋ] in coda position. The CI users in the current study had almost four years of CI experience (*M*=45.5 months), on average, and had better phonetic inventory outcomes than the experienced CI users in Serry and Blamey's (1999) study. This could reflect improvements in technology. Children in the current study with moderate-severe HL had the smallest phonetic inventories as they had not acquired 14 sounds: [k, g, f, v, θ, ð, s, z, ʃ, ʒ, ʧ, ʤ, r, j] in onset and coda position, affecting their overall speech intelligibility.

Consistent with previous findings (Ertmer & Goffman, 2011; Serry & Blamey, 1999), our results indicate that CWHL may not acquire speech sounds in the same order that CWNH do. CWHL were missing both Middle-8 and Late-8 sounds. Variation across CWHL appeared to be related to degree of HL/amplification but further research with a larger sample size would be needed to confirm this. For example, the voiceless alveolar [s] sound was produced by 90% of CIs users; however, it was present in less than 90% of children with mild to severe hearing loss. The acquisition of [s] may be better in CI users due to better high frequency sensitivity with CIs compared to HAs for more severe hearing loss and may depend on the type of speech therapy children receive (Dawson et al., 1995; Tobey & Hasenstab, 1991; Uziel et al., 2007). Ling (2002) noted that therapy for CWHL usually targets voiceless before voiced sounds, but therapy details were not known for participants in the current study.

Clinical Implications

Auditory deprivation significantly affects the speech production of both infants and school aged CWHL (Ertmer & Goffman, 2011; Geers, Brenner, & Tobey, 2011; Geers, Moog, Biedenstein, Brenner, & Hayes, 2009; Nathani & Oller, 2008; Nathani et al., 2007). The current study found speech delay in CWHL and forms the basis for future prospective longitudinal studies of CWHL to determine optimal speech therapy approaches for young CWHL. The current wordlist has significant ramifications for clinical work as it provides clinicians with much information about the speech profile of CWHL as a basis for planning speech therapy. Factors such as hearing aid use (Walker et al., 2013), the frequency with which the child hears certain speech sounds, for example, in the coda position, as well as potential limitations of amplification particularly in the high frequencies, the effectiveness of the hearing aid fitting in providing access to speech cues (McCreery, Brennan, Hoover, Kopun, & Stelmachowicz, 2013), parental input (Ambrose et al., 2014), and the type and extent of therapy all may have contributed to the delayed speech of the participants with HL. The current study found that, despite the use of modern hearing technology, specific active intervention is still required to minimize delays in speech development for CWHL. Children with moderate to severe hearing loss using hearing aids were at particular risk in the current study. Auditory discrimination development can be targeted from infancy to assure that the children can discriminate the sounds using their amplification devices. The production of velars, fricatives, and affricates may need to be specifically taught for CWHL, ideally before children commence school as speech delay may impact the emergence of reading, spelling and writing, with potentially significant consequences for all school learning.

Acknowledgments

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Appendix A

The vowel phonemes of New Zealand English, from Hay, Maclagan, and Gordon (2008) [Table 2.2, p.22]

	Keyword	Tongue		Lips	Length	Words
/i/	FLEECE	high	front	neutral	long	*seat, free, find, key*
/ɪ/	KIT	mid	central	neutral	short	*sit, Sydney, pretty*
/e/	DRESS	high	front	neutral	short	*set, bead, Geoff, many*
/æ/	TRAP	mid	front	neutral	short	*sat, bad, gas, happy*
/a/	START	open	central	neutral	long	*cart, grass, dance, bath*
/ʌ/	STRAUT	open	central	neutral	short	*cut, butter, rough, money*
/ɒ/	LOT	mid	back	round	short	*cot, body, what*
/ɔ/	THOUGHT	high	back	round	long	*cord, caught, call, draw*
/u/	GOOSE	high	central	round	long	*suit, boot, shoot, chute*
/ʊ/	FOOT	mid	central	round	short	*put, book*
/ɜ/	NURSE	front	mid	round	long	*shirt, work, hurt, fern*
/ə/	COMMA	mid	central	neutral	short	*letter, kitten, ago, cotton*

Chapter 3: Speech accuracy in children with mild to profound hearing loss in comparison with typical developing age-peers

Asad, A., Purdy, S. C., Ballard, E. & Bowen, C. (In preparation). Speech accuracy in children with mild to profound hearing loss in comparisons with typical developing age-peers.

This publication is inserted as it will be submitted for publication, with the exception of minor edits and formatting changes to maintain consistency throughout the thesis.

Abstract

Purpose: To compare consonant and vowel production accuracy of children with mild-to-profound hearing loss (CWHL) with that of age-and gender-matched children with normal hearing (CWNH). To compare the phonemic production accuracy of hearing aid (HA) with that of cochlear implant (CI) users. To examine consonant production accuracy in onset and coda positions in three groups of school-age CWHL with mild, moderately-severe, and profound hearing loss.

Method: The speech production of CWHL, *N*=25 was compared with CWNH, *N*=30). Speech samples obtained from a list of 88 words, derived from three standardized speech tests were analyzed using the CASALA (Computer Aided Speech and Language Analysis) program to evaluate participants' phonemic production accuracy, percentages of consonants correct (PCCs) and percentages of vowels correct (PVC).

Results: CWHL and CWNH had similar vowel production accuracy. CWHL had lower PCCs than CWNH. Consonant production accuracy for CI users was better than for HA users. Children with mild hearing loss had similar phonemic production accuracy in onset and coda positions to typical developing children. Consonants in onset position were produced with slightly better accuracy than in coda position by children with moderate-to-severe and profound HL. Children with moderate-to-severe HL were the least accurate in phonemic production.

Conclusions: Differences in speech sound production accuracy across children with mild-to-profound hearing loss might be related to the degree of hearing loss, hearing experience, and the nature of their intervention programs. Children with moderate-to-severe hearing loss need comprehensive assessment and intervention services.

Keywords: phonemic production accuracy, percentage of consonant correct, children with normal hearing, cochlear implant, speech

Introduction

Intelligible and age-appropriate speech is the objective that speech-language pathologists (SLP) and parents have for children with hearing loss (CWHL) in educational settings, and this is a reasonable goal in many instances, given recent improvements in hearing technology (HA and CI), early identification, early fittings, and early intervention programs. Consonant production accuracy in the speech of CWHL is delayed in comparison to typical developing children. In addition, CWHL may acquire consonant production proficiency in an atypical order (Ertmer & Goffman, 2011; Ertmer, Kloiber, Jung, Kirleis, & Bradford, 2012). Even though there is consensus in previous studies that the speech development of CWHL falls behind CWNH, with fricatives and affricates being the most affected sounds, we don't know: 1) which fricatives and affricates are most impacted; 2) if consonants will be produced less accurately in onset and/or coda position by school-age; and, 3) if consonant accuracy will vary in onset and coda position across children with various degree of hearing loss (HL).

In this paper, we present results of a cross-sectional study that was designed to examine the consonant and vowel production accuracy in the New Zealand English (NZE) speech of early school-age children with mild-to-profound HL. Children were identified with hearing loss before the establishment of UNHS in New Zealand. In the literature review that follows, issues in research into the speech accuracy in children with mild-to-severe hearing loss are presented.

Independent and relational analysis

Independent analyses may consist, in part, of a phonetic inventory, where the examiner determines which phones are present in a child's consonant and vowel repertoire. In relational analysis a phonological process (or phonological pattern) analysis is usually conducted, and here a clinician compares the child's speech performance, at word level or beyond, to the adult standards (Smit, 2004; Stoel-Gammon, 2015). Phonological processes are descriptions of simplifications to the adult speech system of phonemic contrasts in which a child may substitute a sound for another (e.g., velar fronting: car =/ta/), omit a sound (e.g., cluster reduction: star = /ta/), or add a sound (e.g., schwa insertion or addition: blue = /bəlu/; back = /bækə/). We will discuss phonological processes further in chapter 4.

A phonetic inventory enables clinicians to identify the sounds (phones) present in a child's repertoire, irrespective of accuracy; while a phonemic inventory is an account of the phones that the child uses contrastively in order to make distinctions between words (Eisenberg & Hitchcock, 2010; Klein, 1984; Stokes, Klee, Carson, & Carson, 2005). The phonemic analysis allows SLPs to compare the child's production accuracy to an age-matched group. SLPs are required to determine the presence of, and then the severity of a child's speech sound disorder (SSD) so as to ascertain eligibility for SLP services, based on Special Education Services. Therefore, clinicians need reliable assessment measures and normative data to make these decisions especially with the large caseloads that they have (Skahan et al., 2007). There is currently no standardized speech assessment test designed to evaluate the speech of CWHL. Our clinical observation suggest that SLPs in New Zealand tend to use standardized tests and quantitative measures as PCC and PVC (Shriberg et al., 1997). PCC has been used as a severity measure in various studies on children with SSD[1] and

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[1] Children with SSD have 'any combination of difficulties with perception, articulation/motor production, and/or phonological representation of speech segments (consonants and vowels), phonotactics (syllable and word shapes) and prosody (lexical and grammatical tones, rhythm, stress and intonation). **International Expert Panel on Multilingual Children's Speech, 2012, page 1**

CWHL (Ambrose et al., 2014; Ertmer & Goffman, 2011; Shriberg, 1993; Shriberg et al., 1997; Shriberg & Kwiatkowski, 1982).

In summary, SLPs consider phonemic accuracy, PCC, and PVC in children with SSD and CWHL in order to establish a baseline pre-therapy and decide on an intervention approach.

Speech accuracy of children with normal hearing (CWNH) and children with mild-to-severe hearing loss fitted with hearing aids (HAs)

Children with normal hearing produce a single-word at around 12 months of age, and acquire a ten-word vocabulary between 12 and 24 months. Various researchers have investigated phonetic production accuracy in either three word positions (pre-vocalic, intervocalic, and post-vocalic, often referred to as “initial”, “medial” and “final”, respectively) or in two positions (initial and final) produced by 75% or more of children in an age group (Sander, 1972; Smit et al., 1990; Stoel-Gammon & Dunn, 1985; Templin, 1957). Dodd, Hua, and Crosbie (2003) reviewed six studies (Poole, 1934; Prather, Hedrick, & Kern, 1975; Smit et al., 1990; Templin, 1957; Wellman, Case, Mengert, & Bradbury, 1931) regarding consonant (not vowel) acquisition and noted consensus across studies of early acquired sounds /m, n, p, b, w/ and late acquired sounds /θ, ð, z, ʤ, ʒ/. According to Smit et al. (1990) typically developing children first acquired initial consonants as nasals, liquid, glide, and stops /m, n, w, p, b, t, d, k, ɡ/ by the age of 3;0 years, fricatives and affricates /j, f, v, s, ʃ, ʧ, ʤ, l/ between 3;6 and 5;0, and lastly acquired fricatives and a liquid /θ, ð z, ɹ/, all with a 75% accuracy criterion. Dodd et al. (2003) examined consonant acquisition in a normative study on 684 British English-speaking children aged between 3;0-6;0 years and found that consonants were acquired by 90% of the children in each age group as follows: 1) stops, fricatives, affricatives, nasals, glides and liquids /p, b, t, d, k, ɡ, m, n, ŋ, f, v, s, z, h, w, l, j, ʧ/ between 3;0-3;11 years; 2) / ʤ, ʒ/ between 4;0-4;11 years; 3) /ʃ/ between 5;0-5;11 years; 4) /ɹ/ between 6;0-6;11 years; and 5) /θ, ð/ in 7;0 and above. This indicates that most consonants are acquired early. In summary, many studies have used independent analysis (phonetic inventory) to examine speech sound development in CWNH.

Gierut et al., (1994) noted that there is a reseach gap in the characterization of phonemic acquisition in typical developing children. Gierut, Simmerman, and Neumann (1994) described the phonemic inventories of 30 children (aged 3;4-5;7) with phonological delay. They identified four related types of phonemic inventories across children: Level I consisted of nasals, stops, and glides; Level II consisted of nasals, stops, glides and fricatives; Level III included an alternation development path (Level IIIA added affricates while Level IIIB added liquids); Level IV children acquire all speech manner of nasals, stops, glides, fricatives, affricates and glides. Recently, Stokes, Klee, Carson, and Carson (2005) emphasized the need to use phonemic inventory in classifying speech disorders. Stokes et al. (2005) examined the productive phonologies of 2-year-old English-speaking typical developing children (*N*=40) in order to provide a phonemic feature hierarchy. They found that children had four levels of phonemic hierarchy which might be useful in the classification of the speech of children with speech disorder.

Auditory stimulation facilitates early speech perception development in infants with normal hearing (Kuhl, 2000, 2004). Consequently, a HL at birth will impede children’s access to the linguistic input that is critical for the development of phonological representations of the spoken words of ambient language (Von Hapsburg & Davis, 2006; Warner-Czyz, Davis, & MacNeilage, 2010). The inability of CWHL to perceive speech sounds will lead to delay in speech acquisition (Tomblin, Oleson, Ambrose, Walker, & Moeller, 2014) which may vary according to the degree of HL, age of identification, and age of HA or CI fitting. For example, Yoshinaga-Itano and Sedey (1998) investigated the speech production of 147 early identified children (0 to 6 months) aged 14 to 60 months who varied in degree of HL from mild to profound. Spontaneous speech samples showed that children with mild to moderate, moderately-severe and severe hearing losses produced almost all the English vowels at the age of 43 months. Many children produced most of the English consonants between 55-60 months, however, children with profound hearing loss lagged behind in their vowel and consonant inventories. They also found that age of identification and degree of HL were the strongest predictors of speech outcomes (Yoshinaga-Itano and Sedey, 1998). Similarly, Ambrose et al. (2014) noted that differences in auditory experience between children with mild-to-severe HL highlighted the need to study these groups of children.

While many studies have explored the speech outcomes of CI users in populations with HL (addressed further below), few have investigated the speech outcomes of HA users (Blamey, Barry, Bow, et al., 2001; Moeller & Tomblin, 2015; Serry & Blamey, 1999; Tobey, Geers, & Brenner, 1994; Wake, Hughes, Poulakis, Collins, & Rickards, 2004). In one of the few examples, Tomblin et al. (2014) conducted a cross-sectional study to examine articulation outcomes of children with mild-to-severe HL (N=180, fitted with HAs) aged three- and five-year. Researchers reported two main findings: 1) on average, HA users had poorer speech outcomes than CWNH; and 2) aided children with mild HL (< 45 dB HL) had significantly better speech production compared to aided children with moderate to severe losses. The authors explained that better speech production for children with mild HL might be related to the early age of fitting, and extended use of the hearing device. Tomblin et al. (2014) also reported that younger children with mild-to-severe HL were significantly less accurate than CWNH (CWHL *M*= 60.01; CWNH *M*=73.79), especially on velars and alveolars ; and that better speech outcomes might be associated with degree of HL (< 45 dB HL) and age of fitting with HAs. These findings were similar to those from Ambrose et al.

(2014), who also investigated speech sound productions of children with mild-to-severe HL (*N*=70) aged two years, in comparison to age- and socioeconomic group- matched CWNH (*N*=37). In addition, Tomblin et al. (2014) revealed that CWHL produced early-8 acquired sounds /b, p, m, n, j, w, d, h/ better than middle-8 sounds /t, k, g, f, v, ŋ, ʧ/ (Shriberg, 1993) while late-8 acquired sounds (ʃ, θ, ð, s, l, r, ʒ) were challenging for CWHL and CWNH. Children who participated in studies by Tomblin et al. (2014) and Ambrose et al. (2014) were part of larger longitudinal study of outcomes of children with hearing loss (OCHL) but Ambrose et al. examined a smaller and younger subset of participants.

In summary, two recent studies examined speech production of pre-school children with mid-to-severe HL who might be at risk for delays in morphosyntax, articulation, phonology, and language. Recently, Moeller and Tomblin (2015) emphasized the need to expand on research on children with mild-to-severe HL as it is currently limited. To our knowledge, there has been no investigation of speech accuracy and type of correctly produced phones in onset (“initial”) and coda (“final”) positions, that may affect the speech intelligibility of school-age children with mild-to-severe HL . The current study attempts to address these issues.

Speech accuracy of CWNH and children with profound hearing loss fitted with cochlear implant (CI)

Contemporary studies show that speech sound production of profoundly deaf children improves after receiving cochlear implants (CI) (Tobey, Geers, & Brenner, 1994; Tye-Murray & Spencer, 1995; Van Lierde et al., 2005). Earlier studies of CI users showed that the speech accuracy of children who were late-fitted with CIs improved only after extended use of the device, in comparison to children who were profoundly deaf and fitted with HAs (Blamey, Barry, et al., 2001; Markides, 1970; Osberger & McGarr, 1982; Tye-Murray &

Spencer, 1995). In subsequent studies, researchers investigated the effects of communication environment, technology, age of identification and intervention, extended use of hearing device, and other variables on speech production in CI users (Connor, Craig, Raudenbush, Heavner, & Zwolan, 2006; Connor, Hieber, Arts, & Zwolan, 2000; Geers, Brenner, & Tobey, 2011). For example, Conner et al. (2000) conducted a longitudinal study of late-identified CWHL to examine the effect of communication modality (oral versus total communication. Oral communication is the development of spoken language while total communication is using multiple modalities to communicate as signs, gestures, speechreading, hearing) on consonant production accuracy for 147 prelingually deaf children who were implanted between age 1;0 and 10;0 years. They used two single word tests, the Arizona Articulation Proficiency (Fudala, 1974) and the Goldman-Fristoe Test of Articulation (Goldman & Fristoe, 1969). They found that children who were implanted before the age of five years had significantly more accurate speech over time compared to children implanted after the age of five. They also noted that there was no significant difference between the oral communication and total communication groups in the rate of speech accuracy progress for children implanted before the age of five years. Warner-Czyz, Davis, and Morrison (2005) conducted a longitudinal case study on one early implanted child (by the age of two) to examine speech production accuracy after an extended use of the CI device. They measured consonants and vowels accuracy in categories: labials (/b, p, m, f, v, w/), coronals (/d, t, n, s, θ, ð, j, l, ɹ, ʃ, ʧ, ʤ, ʒ/), dorsals (/g, k, ŋ/), and vowels (front, central and back). Warner-Czyz et al., (2005) found that the child produced initial labials with (70%) accuracy, initial coronals and dorsals with 30% accuracy, central vowels above 70% accuracy, and back and front vowels with 86% and 69% respectively, after 9 months of CI usage. Thus, they were not able to identify which coronals and dorsals were the most affected. Connor, Craig, Raudenbush, Heavner, and Zwolan (2006) also investigated whether early implanted children would have better phonemic production accuracy than late implanted children (*N*=100, age of implantation 1;0-10;0 years) who used their device between 1 and 12 years. The longitudinal study revealed that there was an early burst in consonant accuracy in children who received their implantation before the age of two. In contrast, this early burst in consonant accuracy was not evident in a Warner-Czyz and Davis (2008) study for early implanted children. Warner-Czyz and Davis (2008) investigated segmental accuracy (consonants and vowels) during the single-word period in four early implanted children (*M age*=1; 2; *M* device experience= 8.5 months) in comparison to CWNH. The accuracy of initial consonants in spontaneous speech samples was examined over six months. They found that both groups had similar vowel accuracy over time. Nevertheless, the speech accuracy gap increased between CI users and CWNH by the end of the study. CWNH were three times more accurate than CI users in producing initial consonants at the beginning of the study, and this increased to being seven times more accurate after 6 months. This suggests that the gap between CWHL and CWNH may widen by school-age. A subsequent study Warner-Czyz, Davis, and MacNeilage (2010) explored the emergence of consonant-vowel sequence (CV) accuracy in conversational speech samples in four early implanted children, in comparison to their typical developing peers (these were the same children as in 2008 study), in order to understand the effect of early hearing depravation on production accuracy. Warner-Czyz et al., (2010) revealed that consonant accuracy improved over the study period, however, CI users made weaker gains than CWNH. This might have been related to early hearing deprivation coupled with variation in word emergence (i.e., 11 to 17 months for CWNH and 18 to 32 months for children with CIs). In addition, children produced consonants more accurately in the most common CV-word combinations (e.g., no, more). This result corresponds with findings by Faes, Gillis, and Gillis (2015) showing that speech accuracy in Dutch-speaking children with CIs (*N*= 9) who were early fitted (range 0;6-1;9) was influenced by word-target complexity and the number of syllables produced in a spontaneous speech sample. Accordingly, clinicans need to consider using words that vary in the number of syllables when assessing speech sound accuracy using single-word tokens.

The literature is equivocal as to whether CI users acquire consonants in a similar order to CWNH. Two studies showed that CI users followed a similar order (Flipsen, 2011; Serry & Blamey, 1999), however, there is also evidence of atypical acquirement (Ertmer and Goffman, 2011; Ertmer et al., 2010). Serry and Blamey (1999) conducted a longitudinal study of nine school-age children with profound HL during the first 4 years of CI usage (6 months interval, *M* age implantation = 3;9). They reported that CI users produced nasals and glides with greatest accuracy, while fricatives and stops were produced least accurately. Ertmer and Goffman (2011) compared production accuracy in six CI users with two years of device experience to their typical developing peers using the First Word Speech Test (Ertmer, 1999). They found that CI users produced onset consonants (e.g., /b/ in ball; /f/ in fun) in an atypical developmental order. Similarly, Ertmer et al. (2012) compared consonant accuracy in initial and final positions for 11 CI children with two years of hearing device experience to eleven age- and gender-matched CWNH (age range 33 -61 months). Children fitted with CIs acquired initial consonants in an atypical order, while final consonants did not show such a tendency. In addition, CI children produced initial consonants more accurately than final ones (Ertmer et al., 2012).

Some studies explored the long term outcomes of CIs in primary and high school aged users (Geers, 2004; Tobey, Geers, Brenner, Altuna, & Gabbert, 2003; Tobey, Geers, Sundarrajan, & Lane, 2011; Tomblin, Peng, Spencer, & Lu, 2008). These studies focused on speech improvement after an extended use of hearing devices, rather than the type of correctly produced sounds in onset and coda positions. Two major findings are documented in the literature: averaged intelligibility performance might be associated with consonant accuracy (Tobey, Geers, Brenner, Altuna, & Gabbert, 2003); and CI users continued to develop speech in the first six years post-implantation but speech production reached a plateau after eight years of device experience (Tomblin, Peng, Spencer, & Lu, 2008).

In summary, there are more studies of pre-school age children fitted with CIs than preschoolers who are HA users. Few studies have examined speech outcomes in children who were fitted with CIs. Overall, studies suggest that children implanted before the age of two may have more similar consonant accuracy to CWNH, but that their speech is delayed compared CWNH. CI users with extended use of hearing device have better speech accuracy, but their speech may plateau after eight years of hearing device experience. Further, CI children acquire consonants in an atypical order in initial position consonants. To date, researchers have neither examined consonant nor vowel accuracy in school-age CI and HA users in onset and coda position, nor compared consonant and vowel accuracy in the speech of HA and CI children who vary in their HL severity.

Current study

Children in the current study were identified with hearing loss before the establishment of UNHS. The aims of the present study were to examine the vowel and consonant production accuracy in the New Zealand English (NZE) speech of early school-age children with mild-to-profound HL in comparison to their CWNH peers; and to examine speech accuracy (in terms of PCC and PVC) in the speech of HA versus CI users to know whether they have similar levels by school-age. We also wanted to explore phonemic accuracy in onset and coda positions in these groups of CWHL: mild, moderate-severe, and profound hearing loss. We expected children with moderate-to-severe HL to have poorer consonant accuracy in onset and coda positions than children with mild and profound HL. This was assumed because children with moderate-to-severe HL received less therapy services at the time of the study, although their severity of HL was greater than that of the mild group. We expected CWHL to have similar vowel accuracy to CWNH.

Three specific research questions were addressed:

1. How accurately do CWHL in NZ produce consonants and vowels in comparison to CWNH aged 5;0 to 7;5 based on a single word test? This question was examined to determine whether CWHL have similar speech accuracy to CWNH or whether they still have SSD, potentially affecting their speech intelligibility.
2. Does speech accuracy differ in this NZ sample of children who are CI versus HA users? If CI users have better speech accuracy than HA users, then CI children might have comparable speech accuracy to that of CWNH by the time they reach school-age. Lower speech accuracy from HA users might be observed, as most of the children were identified late and fitted late with hearing devices, and received less therapy services.
3. Which consonants do NZ children with various degrees of HL produce with less than 90% accurately in onset and coda positions? Addressing this question will provide SLPs with information on whether CWHL still produce singleton consonants more accurately in onset than coda positions in single word tasks, or whether they have similar consonant accuracy regardless of position, by the time they reach school-age. In addition, speech accuracy in onset and coda positions was examined to explore the consonants that are more affected in the speech of children with mild-to-profound HL.

Methodology

Participants

The participants in this study were described in Chapter 2. A brief summary is included here. The participants were a heterogeneous sample of children aged 5;0-7;6 with mild to profound hearing loss (N=25, 11 boys, 14 girls). They were matched for age, gender, and socioeconomic status (SES) to 30 CWNH (11 boys, 19 girls) (see Table 7). Children were recruited from different places and regions New Zealand including schools, deaf education centres, and clinics. The CWHL: a) had no diagnosed impairments other than deafness, b) had typical cognition, with or without speech and language delay, c) used HAs or CIs, d) used spoken language rather than signed communication as their predominant mode of communication, and e) spoke New Zealand English (NZE) at home (but could be bilingual). Children in the control group had no diagnosed congenital or neurological impairments, no history of speech or language disorder, normal hearing according to parental report and distortion product otoacoustic emissions (DPOAE) measured using a Biologic Scout OAE system, and spoke (NZE) at home. Control group children passed the DPOAE hearing screen at four frequencies or more (signal to noise ratio ≥ 6 dB).

The demographic characteristics for the CWHL are summarized in Table 8. All but three of the CWHL were diagnosed before the Universal Newborn Hearing Screening Program began in New Zealand. Three were diagnosed at birth, one in the United States (P20, came to New Zealand at age 2 years) and two in New Zealand (P1 and P3). Each child's most recent audiogram was obtained from their audiologist. An audiologist and an SLP interpreted the audiological reports and described the degree of HL based on the unaided pure-tone average (average pure tone hearing threshold at 500, 1000, and 2000 Hz, PTA).

Table 7. Demographic Characteristics of Children in the Two Groups

	Age		Gender		School decile				Language background	
Part.	Mean (SD)	Range	Boys	Girls	1_3 (N/%)	4_7 (N/%)	8_10 (N/%)	Median	English only	Others
CWHL	6.2 (0.7)	5.1-7.5	11	14	N=7 (28%)	N=6 (24%)	N=12 (48%)	7	19	6
CWNH	6.2 (0.6)	5.0-7.4	11	19	N=8 (27%)	N=6 (20%)	N=16 (53%)	8	23	7

Note: CWHL = children with hearing loss; CWNH = children with normal hearing

Only two children had a unilateral HL: P2 had a moderately severe sensorineural hearing loss and used one conventional HA; P3 had a severe conductive hearing loss due to atresia and used a soft-band bone anchored hearing aid (BAHA). P1, P4, and P5 had bilateral hearing losses but wore unilateral HAs in the worse ear as they had slight or mild hearing loss in the better ear. Eight children wore bilateral HAs (4 females), six used one CI (5 females), and six had two CIs (2 females). Three bimodal device users were grouped with the other CI users for the analysis. In this study, HA means “uses HAs exclusively” while CI means “uses at least one CI”. Children with mild HL were identified late and received less SLP intervention in comparison to the other CWHL. The 12 children with one or two CIs had a minimum of 25 months of CI use.

Subgroups of hearing aid and implant users.

The CWHL were a heterogeneous group and hence were divided into three sub-groups: mild (PTA = 25-40 dB HL), moderate-severe (PTA 41-90 dB HL) HL fitted with one or two HAs, and severe-profound fitted with one or two CIs. Demographic characteristics of HA and CI users are summarized in Table 9.

Table 8. Hearing History, Hearing Instrument for each child with hearing loss

Child	Child	Gender	Age at testing (years)	Age of identification (months)	Unaided thresholds R ear	Unaided thresholds L ear	Sensory aid	Age of first HA fitting (months)	Age of first CI fitting (months)	Duration habilitation services (months)
P1	P1	M	5.3	2	97	27	R: BAHA	24	_	36
P2	P2	F	5.7	68	5	63	L: HA	67	_	_
P3	P3	M	5.5	1	10	72	L: BAHA	65	_	_
P4	P4	F	6.8	66	52	18	R: HA	75	_	_
P5	P5	F	6.3	54	19	33	L: HA*	72	_	1
P6	P6	F	6.3	18	55	47	Bilat HA	18	_	42
P7	P7	M	5.5	30	65	60	Bilat HA	42	_	17
P8	P8	M	5.5	30	62	63	Bilat HA	42	_	17
P9	P9	M	7.5	41	87	83	Bilat HA	43	_	49
P10	P10	F	6.8	36	55	53	Bilat HA	48	_	34
P11	P11	F	5.2	8	75	70	Bilat HA	10	_	50
P12	P12	F	7.1	48	58	60	Bilat HA	60	_	25
P13	P13	M	5.9	48	32	28	Bilat HA	54	_	23
P14	P14	F	6.8	24	100	93	R: CI	27	42	54
P15	P15	F	6.6	25	92	93	R:HA; L: CI	24	54	54
P16	P16	M	6.9	35	107	108	Bilat CI	_	36	46
P17	P17	M	5.8	16	100	100	Bilat CI	17	21	47
P18	P18	M	6.1	17	100	100	Bilat CI	17	20	54
P19	P19	M	6.8	1	100	100	Bilat CI	4	23	54
P20	P20	F	7.3	0	100	100	R: CI	3	12	70
P21	P21	F	5.6	18	83	115	R:HA; L: CI	18	24	43
P22	P22	F	6.8	7	105	105	R: CI; L:HA	12	30	58

P23	P23	M	6.2	24	106	90	R: CI	20	48	32
P24	P24	F	5.2	16	77	87	Bilat CI	16	20	46
P25	P25	F	5.1	14	100	100	Bilat CI	14	22	27
Mean (SD)	**Mean (SD)**			**25.9** **19.7**	**73.7** **31.3**	**74.7** **28.4**		**33** **22.7**	**29.3** **12.9**	40.0 16.5

Note. N = number; CI = cochlear implant; HA = hearing aid; NZSL = New Zealand sign language. L= left; R= right; Soft-band bone anchored hearing aid (BAHA); *Bone conduction unilateral hearing aid

Table 9. Demographic Information for Children with Hearing Loss Including Hearing History, Hearing Instrument Use, and Duration of Services for CI and HA Groups

Characteristic	Cochlear Implant Group	Hearing Aid Group: Mild HL (PTA=25-40 dB HL)	Hearing Aid Group: Moderate-to-Severe (PTA= 41-90 dB HL)
Children, Number	12 (6 bilateral)	4 (2 unilateral HL)	9
Males, Females	5 M; 7 F	1 M; 3 F	5 M; 4 F
Mean age at assessment (SD), [range], month	75 (8.8) [61-88]	74.3 (6.1) [68-82]	73.1 (10.3) [64-90]
Mean age at identification (SD), [range], month	16 (10.1) [0-35]	59.0 (9.6) [48-68]	23.7 (17.4) [0-48]
Unaided Pure-tone average (dB HL) for R and L ears (SD) [range]	98.4 (6.4) [92.5-105]	31.3 (4.1) [26-35]	61.1 (12.86) [41-85]
Mean age at HA fitting (SD), [range], month	14.4 (8.4) [3-27]	67.0 (9.3) [54-75]	39.1 (18.5) [10-60]
Mean age at CI activation (SD), [range], month	29.4 (12.64) [12-54]	_	_
Mean duration of HA use (SD), [range], month	12 (9.7) [4-29]	7.3 (6.9) [1-17]	33.6 (17.7) [1-57]
Mean duration of CI use (SD), [range], month	45.5 (11.7) [25-64]	_	_
Mean duration of HA and CI (SD), [range], month	57.5 (10.5) [53-78]	_	_
Communication method	Oral	Oral	7 Oral , 2 Oral & NZSL
Mean age at receiving therapy services, (SD), [range], month	23.7 (9.4) [6-42]	39.0 (17.4) [30-48]	30.1 (17.4) [10-60]
Mean duration of services,(SD), [range], month	49.8 (9.8) [32-70]	18.0 (26.5) [0-71]	30.0 (13.6) [0-50]

Note. n = number; M= male; F= female; CI = cochlear implant; HA = hearing aid; R=right; L= left; HL = Hearing loss; PTA= pure-tone average; NZSL = New Zealand sign language.

Procedure

Each participant produced all the target words from the 1) Diagnostic Evaluation of Articulation and Phonology (DEAP) (Dodd et al., 2002), 2) Goldman-Fristoe Test of Articulation 2 (GFTA-2) (Goldman & Fristoe, 2000), and 3) Hodson Assessment of Phonological Patterns-Third Edition (HAPP-3) (Hodson, 2004). The three assessments were presented in a randomized order and children were tested in a quiet room. The children's speech was recorded using a high-quality microphone (HC577L) placed 10 cm from the participant's mouth, connected to a Dell LATITUDE laptop with Adobe Audition 5 software, M-Audio preamplifier, and Flip camera.

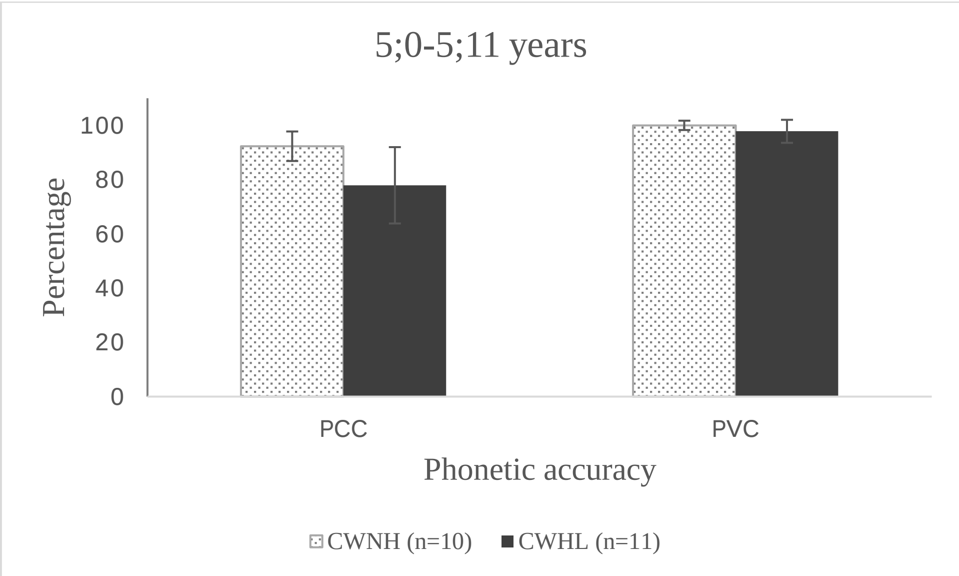
Subsequently, a list of 88 words for analysis was drawn from DEAP, HAPP-3, GFTA-2 (Appendix A, same list used in Ch2). Speech samples of CWHL and CWNH were phonetically transcribed using the International Phonetic Alphabet (IPA), including the extended IPA for transcribing disordered speech (International Phonetic Association,1999) . Transcribed data were entered into the computer software package, Computer Aided Speech and Language Analysis (CASALA) (Serry, Blamey, Spain, & James, 1997). Comparisons between the phonemic transcriptions of the child's production, and the intended adult target generated a single-word percentage of consonant correct (PCC) score to be derived using CASALA. PCC was obtained by dividing the number of phonetically accurate consonants within a child's speech by the total consonants in the sample. The percentage of vowel correct (PVC) score was manually calculated by dividing the number of phonetically accurate vowel productions (i.e., vowels and diphthongs) within the child's speech by the total vowels plus diphthongs in the sample. PCC was averaged in each group of CWHL versus CWNH; and HA versus CI users. Consonants were categorized according to manner of articulation: stops, fricatives, affricates, nasals and approximants (liquids and glides) in onset and coda positions. Results were considered separately for HA and CI users. Phonemic accuracy was computed for each consonant phone to compare consonant accuracy of CI and HA users in onset and coda positions.

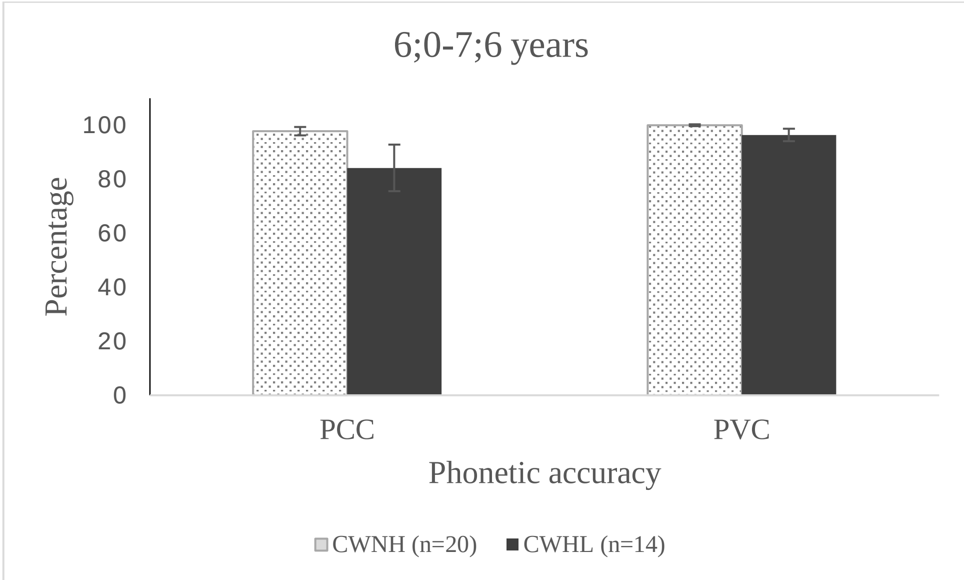
The reliability of phonemic transcription was assessed for 80% of the samples from each group, by two transcribers working independently. Average inter-transcriber agreement between the first author and an experienced SLP was 96.8% (SD = 3.4) across the CWHL. Agreement was 98.0% (SD = 4.7) on average between a student transcriber and the first author for the speech of CWNH. This indicates a high degree of reliability (Shriberg & Lof, 1990).

Results

Speech accuracy in CWHL versus CWNH

Figure 6 shows the average accuracy of production for consonants and vowels for CWNH and CWHL aged 5;0-7;6 years. PCC and PVC scores were within the expected range for typically developing children (Ballard, Wilson, Campbell, Purdy, Yee, 2011; Dodd, Holm, Hua, & Crosbie, 2003). Mean PCC scores were 92% and 97% for the younger and older age groups of CWNH respectively. As expected vowels reached 100% accuracy in both age groups of CWNH. CWHL had similar PVC scores to CWNH in both age groups. Mean PVC scores were 98% and 97% for the younger and older age group of CWHL respectively. CWHL had lower PCCs than CWNH in both age groups, and their mean PCCs were 80% and 84% for the younger and older age group of CWHL respectively.



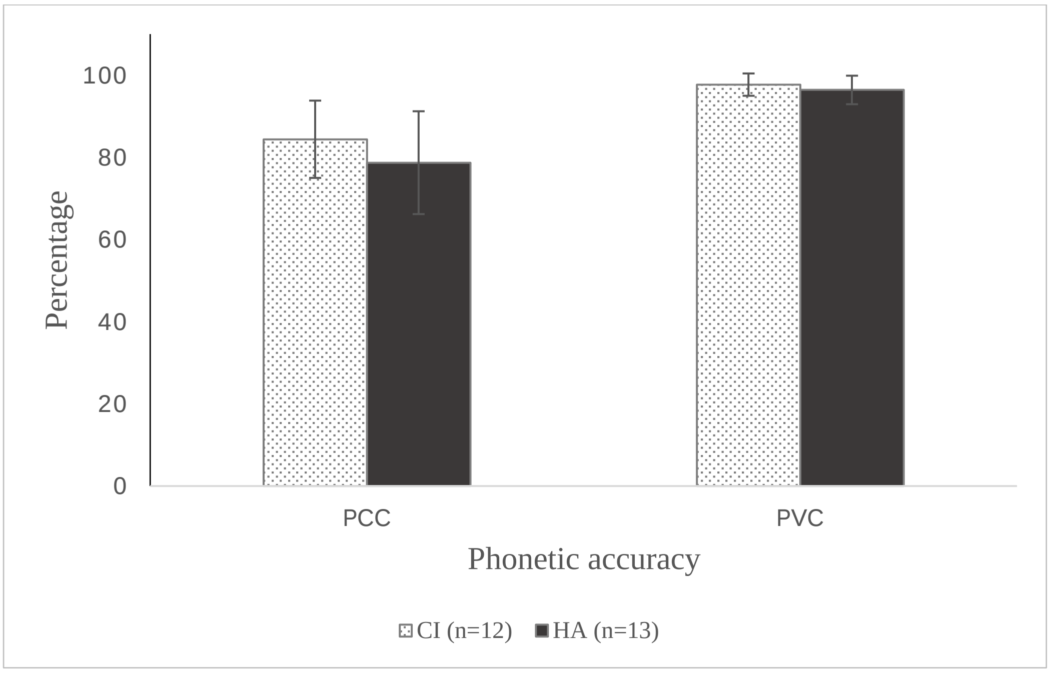


Note. PCC = Percentage of consonants correct, PVC= Percentage of vowel correct

Figure 6. Average PCC and PVC for children with normal hearing and children (CWNH) with hearing loss (CWHL) aged 5;0-7;6 years

Speech accuracy in HA versus CI users

Figure 7 illustrates the PCCS and PVCs for CI and HA users. CI and HA users had similar PVCs of 98% and 96% respectively. However, HA users had lower PCCs than CI users. Mean PCCs were 84% and 79% for CI and HA users respectively.



Note. PCC = Percentage of consonants correct, PVC= Percentage of vowel correct

Figure 7. Average PCCs and PVCs for hearing (HA) and cochlear implant (CI) users

Phonemic accuracy of CI versus HA users: Word Position

CWNH produced all the consonants in onset and coda positions (except /θ/, where the younger group, as they substituted /f/ for /θ/, which was age appropriate for NZE speakers). Children with mild-to-profound HL produced the early-8 consonants as follows: stops /p, b/, nasals /m, n/, fricative /h/, glides and a liquid /w, l/ with ≥ 90% accuracy in onset and coda positions. Phonemic accuracy of stops /t, d, k, g/ fricatives /f, v, θ, ð, s, z, ʃ/, affricates /ʧ, ʤ/

and a liquid /ɹ/ were still delayed in onset and coda positions, and accuracy of production varied in relative to the degree of HL. Children with mild HL had the closest approximation of consonant production to CWNH in onset and coda positions, followed by CI users. Thus, children with moderate-to-severe HL had the least phonemic accuracy in onset and coda positions.

Figure 8 illustrates differences in the production of consonants across children with mild-to-profound HL in onset and coda position. Children with mild HL produced /p, t, d, k, ɡ, f, ʃ, ʤ, j, ŋ/ with ≥ 90% accuracy in onset and coda positions. They produced /v, θ, s, z, ð, ɹ/ with < 90% accuracy in onset and coda positions (except /ʧ/ produced with 100% accuracy in onset position and 88% accuracy in coda position). Children with moderate-to-severe HL produced /p, d/ with ≥ 90% accuracy in the onset position. They produced /t, k, ɡ, f, v, θ, ð, s, z, ʃ, ʧ, ʤ, ɹ, j, ŋ/ with < 90% accuracy in onset and coda positions. However, they produced /t, k, f, v, θ, ð, s, ʃ, ʧ, ʤ, ɹ, j, ŋ/ consonants with better accuracy in the onset than coda position (except for /g/ and /z/). CI users produced /p, d/ with ≥ 90% accuracy in onset and coda position, and /t, f, s, ʃ, ʧ, ʤ, j/ with ≥ 90% accuracy in onset position only. They produced /k, ɡ, v, θ, z, ð, ɹ, j, ŋ/ with < 90% accuracy in onset and coda positions.

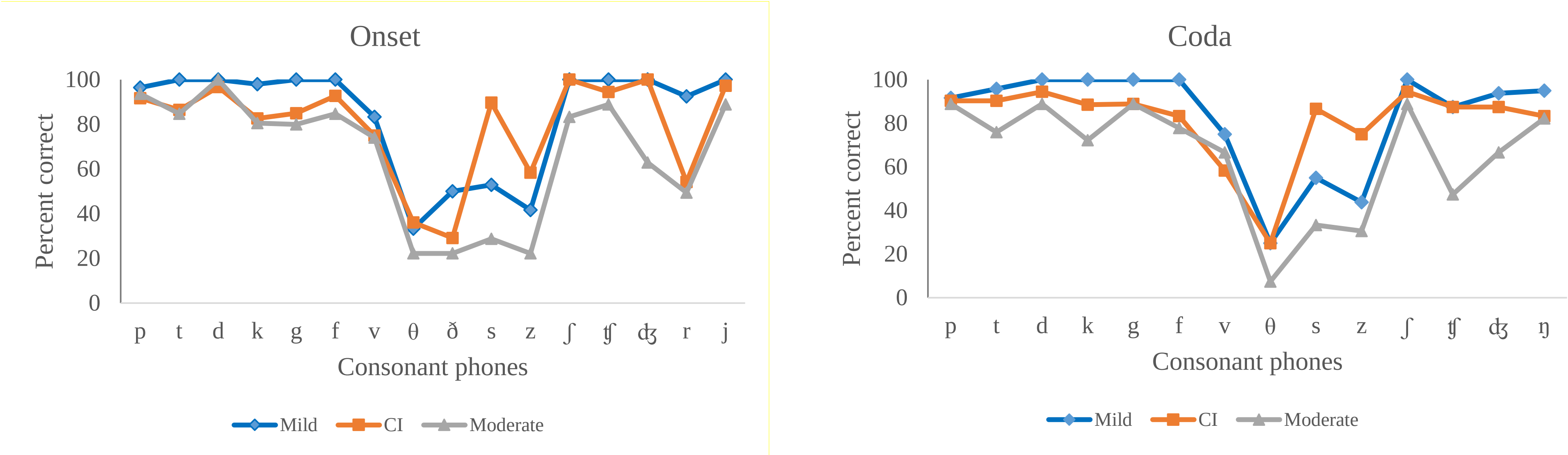


Figure 8. PCCs for consonants in onset and coda positions as produced by children with mild (n=4), moderate-to-severe (n=9), and profound HL (n=12). Blue = Mild HL, grey = Moderate-to-severe HL, orange = CI users.

Discussion

Speech accuracy outcomes

In the current study we investigated the PCCs and PVCs of school-age CWHL in comparison to their peers, PCCs and PVCs in HA versus CI users, and the consonants produced accurately in onset coda position by children with varying degrees of HL. The literature showed that researchers have been interested in speech consonant accuracy in younger CI or HA users (age range 15-61 months), and overall speech production outcomes in CI users in primary and high school. Therefore, it was challenging to compare the current outcomes with previous findings.

Speech accuracy in CWHL versus CWNH

The first goal of the current study was to determine whether school-age CWHL have similar or delayed phonemic production accuracy to CWNH. The PVCs of CWHL were similar to CWNH in both age groups (5;0-5;11 and 6;0-7;6). In their studies, Ambrose et al. (2014) and Warner-Czyz and Davis (2008) also found that younger CWHL (2 to 5 years) had PVCs to CWNH. Greater production proficiency for vowels in comparison to consonants by school-age supports the notion that vowels are acquired earlier in the speech of CWHL (Ambrose et al., 2014; Ertmer, 2001), resembling speech development in CWNH. Ambrose et al. (2014) also explained that greater vowel accuracy in the speech of children with mild-to-severe hearing loss might be related to the higher sonority of vowels as they were ‘perceived as louder than consonants’. The younger age group of CWNH had similar accuracy (PCC=92.3%) to those articulatory proficiency norms reported in the (Ballard, Wilson, Campbell, Purdy, and Yee, 2011) study (PCC=92.5%) for NZE speakers. There are no norms for NZE children aged 6-7 years, however, the current data show that the PCC for older CWNH reached PCCs of 97%. Consistent with previous findings on younger CWHL (Ambrose et al., 2014; Ertmer & Goffman, 2011), our CWHL had lower PCCs than their CWNH peers.

PCCs and PVCs in HA versus CI users

As the current group of children with mild-to-profound HL used different types of hearing technologies, we wanted to know whether hearing devices were associated with the accuracy of phonemic production. Vowel accuracy was similar in HA and CI users. This indicates that vowels were more audible and the bandwidth in HA and CI users allowed them to access (hear and perceive) vowels. However, consonant accuracy (PCC) of CI users was slightly better than HA users. This suggests that CI children might achieve similar PCC levels to CWNH, earlier than HA users. Higher PCs in CI users could be related to three factors. First, children with mild and moderate-to-severe HL who wore HAs were identified late, while children with profound HL who wore CIs were identified earlier than the other two groups (M=59.0; M=23.7 months respectively). Second, CI users had longer hearing experiences than the other two HA using groups as they were fitted early with hearing devices. Finally, CI users received a comprehensive and continuous rehabilitation program from the time of diagnosis with HL, which was not the case for most HA users. This corresponds with the outcomes of previous studies which found that early identification, hearing experience, and rehabilitation play a role in speech outcomes of CWHL (Apuzzo & Yoshinaga-Itano, 1995; Dornan, Hickson, Murdoch, & Houston, 2009; Fulcher et al., 2012; Geers et al., 2002; Tobey, Geers, Sundarrajan, & Lane, 2011; Tomblin et al., 2014; Yoshinaga-Itano, 2004).

Phonemic accuracy of CI versus HA users: Word Position

As children with HAs have lower PCCs than CI users, we wanted to know whether PCCS will vary based on hearing severity. We explored the consonants that children with mild-to-profound HL could correctly produce in onset and coda by school-age. Children with mild-to-profound HL correctly produced consonants /p, b, m, n, w, l/ with visible articulatory movement, which accords with previous findings (Ambrose et al., 2014; Ertmer & Goffman, 2011; Osberger & McGarr, 1982; Serry & Blamey, 1999; Tye-Murray & Spencer, 1995). The current findings support earlier ones that show residual hearing playing a role in speech acquisition (Ambrose et al., 2014; Tomblin et al., 2014; Yoshinaga-Itano & Sedey, 1998) as children with mild HL outperformed children with moderate-to-profound HL. Overall, phonemic accuracy for bilabial stops /p, b/ were better than velar stops /k, ɡ/ in children with moderate to profound hearing loss. Previous studies suggested that less proficiency with velars might be related to limited visual cues for these sounds (Ambrose et al., 2014; Serry & Blamey, 1999). Children with mild HL produced /t, d, k, ɡ/ with ≥ 90% accuracy, whereas the lower accuracy of these sounds by children with moderate to profound HL might indicate a relationship between hearing severity and limited access to auditory stimuli through HAs bandwidth. Surprisingly, both children with mild and profound HL produced affricates /ʧ, ʤ/ with ≥ 90% accuracy in the onset position, and had almost acquired these sounds in the coda position. These findings are in agreement with those of Ertmer and Goffman (2011), who reported that younger CI children with profound HL (age range 33-61 months) produced /ʧ, ʤ/ in the initial position with almost 70% accuracy. Consonant accuracy from the CI children in the current study was higher in onset and coda positions than those of Ertmer and Goffman (2011), probably because they assessed a younger age group. Children with profound HL, fitted with CIs, produced the late-8 acquired sound /s/ correctly, which could potentially be attributed to their early and continuous rehabilitation programs. Most of the CI users in the current study received auditory verbal therapy and clinicians emphasised the "Ling sounds" at the beginning of the therapy which might played a role in better accuracy in the /s/ sound. Similarly, Ertmer and Goffman (2011) emphasised that speech development in CI users might be affected by the order of consonants introduced to the children. Ertmer et al. (2012) identified five possible factors that may lead to an atypical consonant production: differences in auditory perception between CWHL and CWNH, visual and auditory cues play a role in producing early emerging consonants, different consonants provide children with different tactile and kinaesthetic feedback, CI children experience robust hearing at older age so they are not exposed to gradual auditory experience like CWNH, and finally, CWHL acquire sounds in natural settings while CI children acquire sounds in a more structured speech intervention program. Better accuracy of /s, ʧ, ʤ/ in four children with mild HL might be related to auditability and residual hearing. In general, children with mild hearing loss had approximate phonemic accuracy in onset and coda positions to typical developing children. As Ambrose et al. (2014) point out, two year old children with mild hearing loss were most likely to be performing like typical peers. However, most of the children in the Ambrose et al. (2014) study were early identified after establishment of UNHS while in the current study most of the children were late identified prior to UNHS establishment in New Zealand. Hence, we need to caution that better consonant accuracy in children with mild HL was only present in four children and further research is needed with a larger group of participants.

Children with moderate-to-severe HL had poorer phonemic accuracy in onset and coda positions than children with mild HL and profound HL. Consonants in the onset position were produced with slightly better accuracy than in the coda position by children with moderate-to-severe and profound HL. Previous studies show that fricatives and affricates are the most common persisting errors in the speech of children with mild to moderate hearing loss (Elfenbein et al., 1994). Thus, the current study revealed that a range of stops, fricatives, affricates, and liquid were produced with < 90% accuracy which suggest that these children may have more persisting phonological processes and consequently poor speech intelligibility. Lower PCCs in children with moderate-to-severe HL might be related to late age of identification, late age of hearing fitting, receiving less therapy services, inadequate hearing fitting, and/or the restricted bandwidth of hearing aids which limits the audibility. We were not able to examine correlations between these factors and phonemic accuracy due to small number of children with moderate-to-severe HL. One surprising finding was that children with moderate-to-severe HL and profound HL produced /z/ sound slightly more accurately in the coda position than at onset. This might be related to high auditability of voiced /z/ sound in coda position and the morphological structure of target words.

Children with profound HL, who were fitted with CI between the ages of 12-54 months, produced most consonants with 90% accuracy expect /k, ɡ, v, θ, z, ð, r, j, ŋ/ by school age. Tomblin et al. (2008) revealed that CI users continued to develop speech in the first six years post-implantation but speech production reached a plateau after eight years of device experience. The importance of identifying the particular consonants that CWHL struggle to produce correctly by school-age cannot be overstated. As well, evidence-based, data-driven intervention, while they are of pre-school age, is of paramount importance. Future longitudinal studies are needed to examine the effect of using evidence-based therapy from pre-school until school age on speech outcomes of CWHL.

Conclusion

The current study will contribute to clinical practice in determining consonant and vowel accuracy in late-identified school-age children with mild-to-profound HL, in comparison to their CWNH peers. Also, the consonant phones that children with mild-to-profound HL can correctly produce in onset and coda positions. Children with moderate-to-severe HL need a comprehensive speech therapy programme, and clinicians need to stimulate less accurate phonemes during the infancy and toddler period.

Appendix A

Word List used to determine the children's phonetic inventories and production accuracy

No.	Target	Test	No.	Target	Test	No.	Target	Test	No.	Target	Test
1	Bird	DA	23	teeth	DP	45	ˈfeather	DP	67	witch	DC
2	Door	DA	24	watch	DP	46	ˈmonkey	DP	68	dinosaur	DC
3	car	DA	25	ˈorange	DP	47	ˈtoothbrush	DP	69	flower	H3
4	girl	DA	26	school	DP	48	ˈapple	DP	70	fork	H3
5	moon	DA	27	crab	DP	49	knife	DP	71	glove	H3
6	fish	DA	28	ˈbiscuits	DP	50	van	DP	72	gum	H3
7	thumb	DA	29	thank you	DP	51	ear	DP	73	page	H3
8	sock	DA	30	ˈhelicopter	DP	52	this	DP	74	plane	H3
9	chair	DA	31	egg	DP	53	ˈscissors	DP	75	slide	H3
10	jam	DA	32	splash	DP	54	ˈlighthouse	DP	76	smoke	H3

11	ring	DA	33	square	DP	55	ˈzebra	DP	77	star	H3
12	house	DA	34	pig	DP	56	ˈkitchen	DP	78	string	H3
13	foot	DA	35	queen	DP	57	ˈsausage	DP	79	vase	H3
14	ˈtelevision	DA	36	three	DP	58	ˈtiger	DP	80	zip	H3
15	ˈelephant	DP	37	frog	DP	59	ˈrabbit	DP	81	ˈcrayons	H3
16	umˈbrella	DP	38	ˈyellow	DP	60	book	DP	82	green	H3
17	train	DP	39	ˈstrawberry	DP	61	boy	DP	83	nose	H3
18	swing	DP	40	ˈspider	DP	62	shark	DC	84	mouth	H3
19	bread	DP	41	web	DP	63	boat	DC	85	cup	GF2
20	duck	DP	42	sheep	DP	64	jump	DC	86	drum	GF2
21	giˈraffe	DP	43	snake	DP	65	bridge	DC	87	blue	GF2
22	five	DP	44	pram	DP	66	chips	DC	88	clown	GF2

Note. Words are from: a) DEAP Articulation (DA) (14 words), b) DEAP Phonology (DP) (47 words), c) DEAP Consistency (DC) (7 words), d) HAPP-3 (H3) (16 words), and e) GFTA-2 (GF2) (4 words) tests.
(ˈ) stress position for multi-syllabic word

Chapter 4: Phonological process in the speech of school-age children with hearing loss: Comparisons with typical developing age-peers

Asad, A., Purdy, S. C., Ballard, E., Fairgray, L., Bowen, C. (In preparation). Phonological process in the speech of school-age children with hearing loss: Comparisons with typical developing age-peers.

This publication is inserted as it will be submitted for publication, with the exception of minor edits and formatting changes to maintain consistency throughout the thesis.

Abstract

Purpose: This study identified the phonological processes that persist in the speech of early school age children with mild to profound hearing loss using hearing aids (HAs) and cochlear implants (CIs), in comparison to their peers. A second aim was to examine the compare phonological processes of HA and CI users.

Method: Children with hearing loss (CWHL, *N*=25) were compared to children with normal hearing (CWNH, *N*=30) with similar age, gender, linguistic, and socioeconomic backgrounds. Speech samples obtained from a list of 88 words, derived from three standardized speech tests, were analyzed using the CASALA (Computer Aided Speech and Language Analysis) program to evaluate participants' phonological systems, based on lax (a process appeared at least twice in the speech of at least two children) and strict (a processes appeared at least five times in the speech of at least two children) counting criteria.

Results: Distinctive differences were observed between CWNH and CWHL in the amount of processes produced by younger and older CWHL. There was no significant difference in type of phonological processes across age groups based on the lax and strict criteria. CWHL showed a similar trend of age of suppression to CWNH but at a slower rate. Children with HAs and CIs produced similar phonological processes. Final consonant deletion, weak syllable deletion, backing, and glottal replacement were present in the speech of HA users which would affect their overall speech intelligibility

Conclusions: Developmental and non-developmental phonological processes persist in the speech of children with mild to profound hearing loss compared to their peers. The findings indicate that it is important for clinicians to consider phonological assessment in CWHL and the use of evidence-based speech therapy for pre-school CWHL to reduce the presence of non-developmental and non-age-appropriate developmental processes in order to enhance their speech intelligibility.

Keywords: phonological processes, children with normal hearing, cochlear implant, speech production.

Introduction

Newborn hearing screening and modern hearing technologies (digital hearing aids, HAs and cochlear implants, CIs) have created opportunities for improved auditory access to spoken communication and better speech outcomes for CWHL. The question of whether the spoken language proficiency of CWHL eventually reaches the level of age appropriate spoken language of typically developing peers has not yet been answered however (Nicholas & Geers, 2007). Previous studies show that CWHL still perform behind CWNH at a phonetic, phonemic and phonological level despite advances in identification and treatment of HL.

Phonological processes analysis in one of well-known approaches that speech-language pathologists (SLPs) use. Phonological process analysis provides clinicians with a descriptive analysis of the type of speech errors that children have and show whether the child's speech production is following a typical or non-typical developmental sequence. It is essential to gain these information about the child's speech in order to implement evidence based speech therapy approaches. Stampe (1979, p. 1) defined a phonological process as "a mental operation that applies in speech to substitute for a class of sounds or sound sequences presenting a common difficulty to the speech capacity of the individual, an alternative class identical but lacking the difficult property". For example, stop sounds appear to be easier to produce than fricatives. As a result, children substitute fricatives for stops (sun→tun; stopping of fricatives) which is considered a natural phonological process. In addition, young children find it easier to produce a single sound than a sequence of sounds in which they tend to omit one sound (spider → pider; cluster reduction process). Phonological processes have been classified as developmental and non-developmental. Non-developmental processes have been reported in the speech of children with speech disorder and CWHL (Abraham, 1989; Bauman-Waengler, 2012; Bowen, 2015; Flipsen & Parker, 2008; Stoel-Gammon & Dunn, 1985). Based on Stampe (1969) these processes are a natural part of a child's language development in which they gradually disappear ('suppress') from the child's speech in order for them to achieve adult-like phoneme productions. If phonological processes persist beyond the expected age of suppression, children are considered as having a speech disorder and needing speech therapy (Bauman-Waengler, 2012; Grunwell, 1987; Hodson, 2007). There is no consensus on the age of suppression of phonological processes. Most processes tend to be supressed by the age of 5 years or younger in children with typical development (Dodd, Holm, Hua, & Crosbie, 2003; Dodd et al., 2002; Hodson & Paden, 1981; Stoel-Gammon & Dunn, 1985). Dodd et al. (2003) provided normative data for phonological development of 684 (326 boys, 358 girls) British-English speaking children aged 3;0-6;11 years. Dodd et al. (2003) showed that the gliding process is the last process to be supressed at age 5;0-5;11 in typical developing children.

Little is known about the phonological processes that persist in the speech of school age-children with mild-to-profound hearing loss (HL) using different types of hearing technology in comparison to their typical developing peers. Knowledge about phonology ‘speech sound system of language’ (Smit, 2004) of school-age children with hearing loss (CWHL) is needed to identify processes (e.g., final consonant deletion) that affect the child’s speech intelligibility (Hodson & Paden, 1981), and to inform intervention decisions. Intelligible speech and age-appropriate speech and language skills are indicators of better literacy and academic outcomes for CWHL at school (Geers, Brenner, & Tobey, 2011; Geers, Moog, Biedenstein, Brenner, & Hayes, 2009; Gillon & Dodd, 1993). The current study is a descriptive study and aims to add to our knowledge about the phonological process that persist in the speech of children who are hearing aid and cochlear implant users. The results will guide clinicians in developing early intervention programmes for CWHL who have phonology problems.

Phonological processes in the speech of CWHL

There is consensus in previous studies that CWHL who were early identified, early fitted with hearing technology, received appropriate amplification and early intervention are more likely to develop speech that is similar to their typical developing peers (Eriks-Brophy, Gibson, & Tucker, 2013; Ertmer & Goffman, 2011; Ertmer & Inniger, 2009; Warner-Czyz et al., 2005). Although these studies show overall progress in the speech outcomes of CWHL, the phonological development of CWHL tends to lag behind typical developing children (Abraham, 1989; Dodd, 1976; Flipsen & Parker, 2008). Phonological processes might vary across children based on varying degrees of HL, age of diagnosis, intervention program, and the amount and quality of acoustic information that CWHL may gain through their HAs and/or CIs. Children with mild to moderately severe HL have: 1) consonant articulatory errors which particularly affect fricatives and affricates (Elfenbein et al., 1994); 2) phonological processes that persist in their speech including substitutions, distortions, and omission of consonants (Huttunen, 2001; Moeller et al., 2010); 3) almost accurate vowel production (Moeller, Hoover, Putman, Arbataitis, Bohnenkamp, Peterson, Lewis, et al., 2007a; Moeller, Hoover, et al., 2007b; Yoshinaga-Itano & Sedey, 1998); 4) overall intelligible speech (Eisenberg, 2007; Elfenbein et al., 1994). On the contrary, the speech of children with severe to profound HL has been described as: 1) having consonant articulatory errors which affect stops, fricatives, affricates, and liquids (Hudgins & Numbers, 1942; Ling, 2002; Smith, 1975); 2) having consonant errors including cluster reduction, final consonant deletion, stopping, fronting, devoicing of stops, liquid simplification, and gliding (Abraham, 1989; Dodd, 1976; Hudgins & Numbers, 1942; Markides, 1983; Meline, 1997; Oller, Jensen, & Lafayette, 1978; Osberger & McGarr, 1982; Smith, 1975; Stoel-Gammon, 1983); 3) having vowel errors including substitutions, diphthongization, and prolongation; and 4) being less intelligible especially if they were late identified and fitted with hearing technology (Ertmer, 2011; Markides, 1970; Peng et al., 2004). Speech characteristics of children with severe-profound HL are improved after cochlear implantation.

CI technology provides profoundly deaf children with improved perception for speech sounds enabling them to acquire and produce linguistic units and enhancing their overall communication abilities (Van Lierde et al., 2005). Contemporary studies show that early implanted children with extended device usage gain better speech production accuracy. CIs influence children’s ability to recognise and monitor their own speech production and develop an adult-like phonological system (Connor et al., 2006; Tobey, Geers, Brenner, Altuna, & Gabbert, 2003; Tye-Murray, Spencer, & Woodworth, 1995; Warner-Czyz, Davis, & MacNeilage, 2010). However, CI users still have speech delay in comparison to their typical developing peers. There is consensus that CWHL have a systematic, rule-governed phonological system which consists of developmental and non-developmental phonological processes that persist beyond expected age (Buhler, DeThomasis, Chute, & DeCora, 2007; Chin & Pisoni, 2000; Doble, 2006; Law & So, 2006; Moeller et al., 2010; Van Lierde et al., 2005). Since 2000, at least 10 studies have investigated the phonological processes in CWNH, including CI and/or HA users as outlined in Table 10. Some authors in previous studies prefered to use the term 'phonological pattern' instead of 'phonological processes'. The labels for the patterns they identified are the same to those previously described in terms of developmental and non-developmental phonological processes (e.g., stopping, cluster reduction, backing etc.). Studies differ in the reported phonological skills of CWHL, which might be related to study design, demographic variables, early age of identification, early device fitting and analysis criteria. Some studies have investigated phonological processes in English-speaking children while others identified processes in Cantonese or Dutch speaking CWHL. It was challenging to conclude which processes were more affected as some researchers have grouped processes under categories (e.g., addition/prolongation, omission/simplification, and consonant substitution) and other researchers did not define the processes. For example, Paatsch, Blamey, and Sarant (2001) used the Computer-Aided Speech and Language Assessment (CASALA) which is a useful program for facilitating phonological processes analysis but it was not clear what the researchers mean by 'other diacritics' and 'cluster error' processes.

In the majority of reviewed studies, cluster reduction, stopping, fronting, assimilation, diphthong simplification, gliding, unstressed syllable deletion (weak syllable deletion), and final consonant deletion were common developmental phonological processes in the speech of CI users (Table 10). In general the most common non-developmental processes in the speech of CI users were initial consonant deletion, backing, glottal replacement and vowel errors however Law and So (2006) reported that non-developmental processes were not present in CI children. Table 10 showed that only two studies investigated phonological process in late identified children with mild-moderate/moderate HL who were fitted with HA (Huttunen, 2001; Moeller et al., 2010). Moeller et al. (2010) observed stopping and cluster reduction as the most common processes. Huttunen (2001) showed that vowel substition and distortion, syllable addition, and consonant substitution were more common process in chilldren who were HA users than CWNH. Huttunen (2001) provided clinicians with broad idea about the type of errors occurring in CWHL, but in order to inform therapy and improve speech intelligibility in CWHL a thorough investigation of the speech of CWHL is needed.

Four studies compared phonological processes in the speech of HA and CI users (Eriks-Brophy et al., 2013; Law & So, 2006; Paatsch et al., 2001; Van Lierde et al., 2005). Van Lierde et al. (2005) showed that phonological processes were similar for profoundly deaf HA and CI users, however, cluster reduction, stopping and backing were more common in the HA children. The similarity in processes between the groups (HA and CI) might be related to late age of implantation (M=5.6 years). A year later, Law and So (2006) investigated processes in a younger age group (M=5.6) of profoundly deaf children and found that CI users had fewer processes than HA users. Stopping, fronting, and final consonant deletion were the most common processes across groups. Law and So (2006) reported the phonological skills of CI children were better than HA users with similar degree of HL which highlights the benefit of CI device use for speech outcomes of profoundly deaf children. Only Paatsch, Blamey, and Sarant (2001) and Eriks-Brophy et al. (2013) studies examined the phonological processes in children with mild-severe HL who were fitted with HAs to children with profound HL who received CI. Participants in Paatsch, Blamey, and Sarant’s (2001) study were diagnosed with HL pre-UNHS while children in the study by Eriks-Brophy et al. (2013) were diagnosed with HL post-UNHS. Paatsch, Blamey, and Sarant (2001) combined the data on phonological processes of CI and HA users and no comparison was made between the two groups.

However, Eriks-Brophy et al. (2013) emphasized the need to examine the phonological skills of pre-school children with mild-severe bilateral HL in comparison to CI children as speech errors may reduce with early identification, usage of hearing technology, and early intervention. They found that there was a significant difference between CWHL and CWNH; CWHL used more cluster reduction, initial voicing, and final devoicing than CWNH, and there was no significant difference between HA and CI children on KLP-2 standard scores (phonological processes). Fairgray, Purdy, and Smart (2010) investigated speech language therapy outcomes in seven late-identified children with moderate to profound HL (age range 5.5-17.7) who were fitted with hearing technology (HA=2; CI=5). Children had some speech errors beyond the normally expected age and some had very poor speech intelligibility, affecting their ability to participate in auditory/oral learning and social activities. Articulation errors measured using the Hodson Assessment of Phonological Patterns-3 (HAPP-3) ranged from 7 to 74% (mean 37, SD 28%) pre-therapy and 6 to 37% (mean 16, SD 12%) after 20 weeks of weekly therapy. Four of the CI children had mild phonological processes pre-therapy and after therapy children had minor errors. However, phonological processes of children with moderate HL fitted with HA improved from moderate to mild delay post-therapy. The findings of this exploratory study suggest that children with HL have speech errors beyond the age where these errors typically resolve, as reported in international studies, and further research is urgently needed.

In summary, the analysis of phonological processes is a well-known approach to describing the speech errors of children with speech difficulties. As previous studies vary in sample size, participants' age, age of identification, age of device fitting, assessment method, phonological process analysis, and intervention approach used with CWHL, the comparison across studies was challenging. There are well-established studies of phonological skills of children who are CI users. These researchers found that processes in pre-school CI children were generally developmentally appropriate based on hearing age (Flipsen & Parker, 2008) which indicates that CI children may catch up after extended use of their hearing device. Surprisingly, there are few studies investigating the phonological processes that persist in the speech of school age-children with mild-to-profound HL using different types of hearing technology in comparison to their typical developing peers. In addition, few studies have compared processes in the speech of CI and HA users. Speech language pathologists need to be aware of the phonological processes that persist in speech of CWHL as it is known the phonological disorders affect intelligibility. These considerations form the basis for the current study which explored the phonological process that most commonly persist in the speech of school-age children with various degrees of HL, in comparison to CWNH.

Current study

Children in the current study were identified with hearing loss before the establishment of UNHS. The aim of the current study was to identify the most common phonological processes that persist in the speech of school-age CWHL in comparison to their peers. Both developmental and non-developmental processes were examined. This study also compared the phonological processes persisting in the speech of hearing aid users and those using CIs.

Specific research questions were used to:

1. Compare the phonological processes present in CWHL and CWNH:
    a. What type of developmental and non-development phonological processes are present in the speech of children with mild to profound HL in comparison to CWNH aged 5;0 to 7;5?
    b. Do phonological processes differ in younger (5;0=5;11) versus older (6;0 – 7;6) CWHL and CWNH?
2. Compare the phonological processes persisting in CI and HA users
    a. Do phonological processes differ in children with CIs versus hearing aids?
    b. What type of processes that are more likely to affect speech intelligibility of CWHL?

Table 10. Summary of studies about the phonological process present in the speech of hearing aid and/or cochlear implant users

Authors	Subjects	Method	Results: Phonology
Chin & Pisoni (2000)	A single case CI m.a.: 5.8 yrs Fitted with CI at 3;10	• A longitudinal study • Data collection: Productions of a set of 23 spontaneous single words • Phonology criteria: - No specific criteria - Describe type of errors • Describe the phonological system at two years of CI usage	• Developmental phonological processes: stopping of fricatives, gliding of liquids • Non-developmental process: the child substituted palatal fricative /ʃ/ with /s,t,k/
Huttunen (2001)	10 Finnish-speaking moderately bilateral sensorineural HL m.a.: 5.1 5 CWNH, Age: 3 yrs	• Cross-sectional study • Data collection: Articulation screening test (pictures) • Examine the phonological development in children with moderate HL in comparison to younger typical developing children	• CWHL had more phonological processes than younger CWNH • Phonological process: o Vowel substitution and distortion o Addition/prolongation (phoneme and syllable addition, prolongation including consonants and vowels o omission/simplification (final consonant deletion, initial consonant deletion, cluster reduction, syllable omission o Consonant substitution (fronting, stopping, voicing, devoicing, assimilation, and denasalisation)
Paatsch et al. (2001)	12 CWHL 6 profound HL - CI 3 severe HL - HA 3 moderate HL – HA m.a.: 8.4	• Cross-sectional study • Data collection: Spontaneous speech sample pre-and post-training	• Phonological process were combined for HA and CI users • Speech errors were present on consonants and vowels • The most frequent vowel error was nasalization

	Age range of: - HA fitting: 0;03 – 3;4 - CI fitting: 1;10- 4;10	• Phonology criteria: • Relative index of unintelligibility which is the ratio of number of occurrences to total number of words based on. • The effectiveness of articulation training on the production of phoneme in connected speech	• Phonological processes (most frequent): cluster reduction, fronting, final consonant deletion, and stopping
Van Lierde et al. (2005)	15 prelingually Dutch deaf children * <u>Groups:</u> - 6 HA users: m.a. 10.6 yrs - 9 CI users: m.a.: 8.10 yrs - m.a. of implantation: 5.6yrs	• Cross-sectional study • Data collection: Picture naming task • Phonology criteria: if the process was present in four or more words in the child's speech • Compare overall articulation, intelligibility, resonance, and voice characteristic in the speech of hearing and cochlear implant users	• Phonological processes were separately reported for CI and HA users • Both HA and CI users had similar use of the following phonological process: final consonant deletion, initial consonant deletion, cluster reduction, stopping, backing, replacement liquid /r/, devoicing, assimilation, reduplication • Cluster reduction, stopping and backing were more significant in the speech of HA users
Law and So (2006)	14 Cantonese-speaking children with profound HL * <u>Groups</u>: - 7 HA users: m.a. 5.6 yrs - 7 CI users: m.a.: 5.7 yrs	• Cross-sectional study • Data collection: Phonology Segment Phonology Test and spontaneous speech sample	• Phonological processes were separately reported for CI and HA users • CI users had fewer processes than HA users • Non-developmental processes: o 86% of HA users produced non-developmental processes (e.g., initial consonant deletion and backing).

	Age range of: - HA fitting: 0;11- 4;0 - CI fitting: 2;4- 4;02 m.a. of implantation: 3.0yrs	• Phonology criteria: if the process has been present twice in the child’s speech • Explore the phonological skills of two groups of profoundly deaf children (CI vs. HA users)	o Not present in CI users • Phonological process across groups (most common): stopping, fronting, and final consonant deletion.
Doble (2006)	7 CWHL CI: received at 8-12 months m.a.: 2.8	• Longitudinal study • Data collection: spontaneous speech sample (Child-parent interaction) • Phonology criteria: process occurred at least 10% of the time • Examine speech and language development outcomes of early implanted children for 2 years post-implantation.	• Phonological processes 12 months pre-implantation (most common): final consonant deletion, cluster reduction, monophthongization, fronting, reduplication, and substitution • Phonological processes 18 months post implantation (most common): cluster reduction, final consonant deletion, initial consonant deletion (non-developmental), and monophthongization.
Buhler, DeThomasis, Chute, and DeCora (2007)	5 CWHL - CI received: by 2 yrs (except 1 child age 12 months) m.a.: 4.5	• Cross-sectional study • Data collection: Goldman–Fristoe Test of Articulation-2 (GFTA-2) and Khan-Lewis Phonological Assessment-2 (KLP-2; Khan & Lewis, 2002)	• Phonological process used by 4 out of 5 children: final consonant deletion, stopping, cluster simplification, liquid simplification, velar fronting, palatal fronting, deaffrication, initial voicing • Children exhibited non-developmental processes as follows: initial consonant deletion, backing and affrication

		• Phonology criteria: used at least one process on at least 40% of the time	
Flipsen and Parker (2008)	6 prelingually deaf children - m.a. of CI fitting: 2.3 - m.a at testing: 5.0	• Longitudinal study • Data collection: Conversational speech sample • Phonology criteria: percentage of occurrence of each processes were compared to frequencies for children with normal hearing • Examine the overall frequency of occurrence for developmental and non-developmental phonological processes in the speech of CWHL	• CI users had similar phonological processes to children with normal hearing • Phonological processes (most common): cluster reduction, stopping, liquid simplification, final consonant deletion, unstressed syllable deletion, and fronting • Non-developmental processes: initial consonant deletion, vowel substitution, glottal stop substitution-medial, vowel neutralization, and backing-initial
Moeller et al. (2010)	- 4 children with mild-moderate sensorineural HL (Late identified) Age range: 28-41 followed till 84 mos - 10 CWNH: followed from 4-60 mos	• Longitudinal study • Cross-sectional study • Data collection: Goldman–Fristoe Test of Articulation-2 (GFTA-2) • Phonology criteria: No criteria – just observation • Describe phonological and morphological	• Stopping and omission (postvocalic and in blends) were the most common observed process • CWNH substitute a fricative for another fricative or use lateralization or fronting

		development in four children with mild-moderate HL in comparison to their typical developing peers	
Eriks-Brophy et al. (2013)	- 25 CWHL 10 HA users (1 mild, 2 moderate, 5 moderate-severe, 2 severe HL) 15 unilateral CI users (3 severe-profound HL, 12 profound HL) - 35 CWNH Age range for groups: 36 - 60 mos - m.a. of HA fitting: 16.6 - m.a. of CI fitting: 24.3	• Cross-sectional study • Data collection: Goldman–Fristoe Test of Articulation-2 (GFTA-2) and Khan-Lewis Phonological Assessment-2 (KLP-2; Khan & Lewis, 2002) • Phonology criteria: KLP-2 standard scores, Average use of processes • Investigate articulatory and phonological processes in HA and CI users in comparison to typical developing peers. In addition, compare phonological processes in HA and CI users overtime	• Significant difference between CWHL and CWNH for two processes: o Reduction process (final consonant deletion, syllable reduction, stopping, cluster simplification, liquid simplification) o Voicing (initial voicing and final devoicing) • Non-developmental processes in CWHL: initial consonant deletion, deletion of medial consonant, nasalization, affrication, glottal replacement • No significant difference between CWHL and CWNH usage of place and manner of articulation process (Velar fronting, palatal fronting, deaffrication) • Significant difference between CI and HA users on GFTA-2 standard scores but no difference between groups on KLP-2 standard scores

Note. CWHL = children with hearing loss; CWNH = children with normal hearing; m.a. = mean age; HL = hearing loss; mos=months; CI = cochlear implant

Methodology

Participants

Participants in this study were described in Chapter 3. A brief summary is included here. Participants were a heterogeneous sample of children aged 5;0-7;6 with mild to profound HL (N=25, 11 boys, 14 girls) matched for age, gender, and socioeconomic status (SES) to 30 CWHL (11 boys, 19 girls) (Table 11). Children were recruited from different places and regions in New Zealand including schools, deaf education centres and clinics. The CWHL: a) had no diagnosed impairments other than deafness, b) had typical cognition, with or without speech and language delay, c) used HAs or CIs, d) used spoken language rather than sign communication as their predominant mode of communication, and e) spoke New Zealand English at home (but could be bilingual). Children in the control group had no diagnosed congenital or neurological impairments, no history of speech or language disorder, normal hearing based on parental report and distortion product otoacoustic emissions (DPOAE) measured using a Biologic Scout OAE system, and English spoken at home. Control group children passed the DPOAE hearing screen at four frequencies or more (signal to noise ratio ≥ 6 dB). Demographic characteristics for CWHL are summarized in Table 12. All but three of the CWHL were diagnosed before newborn hearing screening began in New Zealand. Three were diagnosed at birth, one in the United States (P20, came to New Zealand at age 2 years) and two in New Zealand (P1 and P3). The child's most recent audiogram was obtained from the child's audiologist. An audiologist and a speech language pathologist (SLP) interpreted the audiological reports and described the degree of HL based on the unaided pure-tone average (average pure tone hearing threshold at 500, 1000, and 2000 Hz, PTA). Only two children had unilateral HL: P2 had moderately severe sensorineural and used one conventional HA; P3 had severe conductive HL due to atresia and used a soft-band bone anchored hearing aid (BAHA). P1, P4, and P5 had bilateral HL but wore unilateral HAs in the worse ear as they had slight or mild HL in the better ear. Eight children wore bilateral HAs (4 females), six used one CI (5 females), and six had two CIs (2 females). Three bimodal device users were grouped with the other CI users for analysis. In this study, HA means “uses HAs exclusively” while CI means “uses at least one CI”. Children with mild HL were late identified with HL and received less therapy services in comparison to the other CWHL. The 12 children with one or two CIs had a minimum of 25 months of CI use.

Type of therapy services.

Parents reported the therapy service that the children received. For HA users (*n*=13), 54% received services from an Advisor on Deaf Children (AODC), 23% received services from SLPs and AODCs but 23% did not receive any service. All CI (*n*=12) users received services from a multidisciplinary team that included early childhood teachers as well as SLPs, AODCs, Auditory Verbal Therapists (AVTs), and Resource Teachers of the Deaf (RT).

Procedure

The assessment tests and equipment

Children were tested in a quiet room and assessments were presented in randomized order. Children were asked to name the target pictures and/or objects from the Diagnostic Evaluation of Articulation and Phonology (DEAP) (Dodd et al., 2002), Goldman-Fristoe Test of Articulation 2 (GFTA-2) (Goldman & Fristoe, 2000), and Hodson Assessment of Phonological Patterns-Third Edition (HAPP-3) (Hodson, 2004). Children’s speech was recorded using a high-quality microphone (HC577L) placed 10 cm from the participant’s mouth, connected to a Dell LATITUDE laptop with Adobe Audition 5 software, M-Audio preamplifier, and Flip camera.

Sample transcription and reliability

A word list of 88 words was established from DEAP, HAPP-3, GFTA-2 (Appendix A) that would comprehensively identify the speech difficulties of CWHL. The word list consisted of 63 monosyllabic words, 19 disyllabic words, and 6 multisyllabic words. Speech of CWHL and CWNH was phonetically transcribed by the first author using the International Phonetic Alphabet (IPA) system, including the extensions for describing disordered speech (Copyright 2005 by the International Phonetic Association).

Transcribed productions were used to establish the phonology profile of the school-age CWHL and CWNH. The first investigator entered the transcribed data into the computer software package CASALA (Computer Aided Speech and Language Analysis; Serry, Blamey, Spain, & James, 1997, version 5.0). The CASALA program compares the target and transcribed phonemes to obtain phoneme accuracy scores and perform phonological process analyses. The data were analysed for the presence of 44 phonological processes based on the CASALA program (Appendix B). The program considers all occurrences of speech errors. For example, if the child produces fish = /bɪʃ/, the /f/ →/b/ substitution is counted as two processes, stopping and voicing.

The reliability of phonemic transcription was assessed for 80% of the samples from each group, with two transcribers working independently. Average inter-transcriber agreement between the first author and the experienced SLP was 96.8% (SD = 3.4) across the CWHL. Agreement was 98.0% (SD = 4.7) on average between a student transcriber and the first author for the speech of CWNH. This indicates a high degree of reliability (Shriberg & Lof, 1990).

Data Analysis

Previous studies differed on the criteria used to consider a processes present in the child's speech. For example, Dodd et al (2003) considered a process to be present if it occurred on five or more times within an individual's speech and was used by 10% of typical developing children. However, we investigated the phonological processes in CWHL who may have different types of processes than CWNH. Therefore, adhering to only a strict criterion (5 times occurrence, Dodd et al. 2003) may not capture processes that occur less in the speech of CWHL which are likely to affect their speech intelligibility.

Table 11. Demographic Characteristics of Children in the Two Groups

Part.	Age		Gender		School decile				Language background	
	Mean (SD)	Range	Boys	Girls	1_3 (N/%)	4_7 (N/%)	8_10 (N/%)	Median	English only	Others
CWHL	6.2 (0.7)	5.1-7.5	11	14	N=7 (28%)	N=6 (24%)	N=12 (48%)	7	19	6
CWNH	6.2 (0.6)	5.0-7.4	11	19	N=8 (27%)	N=6 (20%)	N=16 (53%)	8	23	7

Note: CWHL = children with hearing loss; CWNH = children with normal hearing

Table 12. Hearing History, Hearing Instrument for each child with hearing loss

Child	Child	Gender	Age at testing (years)	Age of identification (months)	Unaided thresholds R ear	Unaided thresholds L ear	Sensory aid	Age of first HA fitting (months)	Age of first CI fitting (months)	Duration habilitation services (months)
P1	P1	M	5.3	2	97	27	R: BAHA	24	_	36
P2	P2	F	5.7	68	5	63	L: HA	67	_	_
P3	P3	M	5.5	1	10	72	L: BAHA	65	_	_
P4	P4	F	6.8	66	52	18	R: HA	75	_	_
P5	P5	F	6.3	54	19	33	L: HA*	72	_	1
P6	P6	F	6.3	18	55	47	Bilat HA	18	_	42
P7	P7	M	5.5	30	65	60	Bilat HA	42	_	17
P8	P8	M	5.5	30	62	63	Bilat HA	42	_	17
P9	P9	M	7.5	41	87	83	Bilat HA	43	_	49
P10	P10	F	6.8	36	55	53	Bilat HA	48	_	34
P11	P11	F	5.2	8	75	70	Bilat HA	10	_	50

P12	P12	F	7.1	48	58	60	Bilat HA	60	_	25
P13	P13	M	5.9	48	32	28	Bilat HA	54	_	23
P14	P14	F	6.8	24	100	93	R: CI	27	42	54
P15	P15	F	6.6	25	92	93	R:HA; L: CI	24	54	54
P16	P16	M	6.9	35	107	108	Bilat CI	_	36	46
P17	P17	M	5.8	16	100	100	Bilat CI	17	21	47
P18	P18	M	6.1	17	100	100	Bilat CI	17	20	54
P19	P19	M	6.8	1	100	100	Bilat CI	4	23	54
P20	P20	F	7.3	0	100	100	R: CI	3	12	70
P21	P21	F	5.6	18	83	115	R:HA; L: CI	18	24	43
P22	P22	F	6.8	7	105	105	R: CI; L:HA	12	30	58
P23	P23	M	6.2	24	106	90	R: CI	20	48	32
P24	P24	F	5.2	16	77	87	Bilat CI	16	20	46
P25	P25	F	5.1	14	100	100	Bilat CI	14	22	27
Mean (SD)	**Mean (SD)**			**25.9** **19.7**	**73.7** **31.3**	**74.7** **28.4**		**33** **22.7**	**29.3** **12.9**	40.0 16.5

Note. N = number; CI = cochlear implant; HA = hearing aid; NZSL = New Zealand sign language. L= left; R= right;
Soft-band bone anchored hearing aid (BAHA); *Bone conduction unilateral hearing aid

The phonological profiles of CWHL and CWNH were established based on two criteria (lax and strict). For the lax criterion, a process was considered present if it appeared at least twice in the speech of at least two children. For the strict criterion, a process was considered present if it appeared at least five times in the speech of at least two children. Differences in phonological processes produced across groups (younger vs. older, HA vs. CI) were tested using Chi-square tests of independence analysis. The CASALA analysis included 21 phonological processes. Five of these processes (other fronting, other backing, other diacritics, cluster errors, frication) were reassigned as shown Table 13. The category of phonological processes used in the current study described all the mismatches that were perceptually apparent between the child's speech and the target (adult speech).

The phonological processes compiled for this study included 14 processes produced by at least two children in a group (younger vs. older, HA vs. CI) classified as: 1) eleven developmental processes (cluster reduction, cluster simplification, final consonant deletion, weak syllable deletion, stopping, velar fronting, gliding, devoicing, voicing, deaffrication, assimilation); 2) and three non-developmental phonological processes (backing, glottal replacement, affrication) (Ball & Kent, 1997; Bauman-Waengler, 2012; Bowen, 2015; Barbara Dodd et al., 2003; Grunwell, 1987; Hodson & Paden, 1981; Rvachew & Brosseau-Lapré, 2012) (Table 13). Consonant processes such as epenthesis, migration, and palatal fronting and vowel processes (distortion, monophthongization, and diphthongization) were not included as few CWHL had these processes and hence they did not meet either the lax or strict criteria. Results were considered separately for younger (5;0-5;11) and older (6;0-7;6) children. Fricative simplification is when the child replaces the dental fricatives /θ/ with labiodentals /f/. In New Zealand English (NZE) this is not considered as a speech error but rather a dialect variation. This view is clinically supported by other researchers (Ballard, Wilson, Campbell, Purdy, & Yee, 2011; Gordon et al., 2004; Moyle, 2005). In addition, Ballard et al. (2011) pointed out that lisping was more frequent in the speech of typical developing NZ children which persist until seven years. The examiner in this study evaluated the participants' performance according to standard NZE and therefore fricative simplification and lisping (considered articulatory shift) (Hodson, 1980) were not considered in the current study.

A summary of the phonological processes examined in the current study is included in Table 14. Table 14 includes processes, definitions, and anticipated age of suppression based on the literature. The age of suppression was adapted from Dodd et al. (2003) and McLeod, Doorn, and Reed (2001a). No study has investigated the age of suppression for cluster simplification, however, McLeod, Doorn, and Reed (2001a) reported that cluster simplification occurred in sequence with cluster reduction. Therefore, we considered age of suppression to be similar to cluster reduction. The percentage of children producing a process twice or five times in their speech was computed to determine the phonological profile of younger and older children and HA and CI users.

Table 13. Processes from CASALA program that were reassigned

No.	Category in CASALA	Modification	Rationale	Examples/ References
1	*Other fronting*: a consonant is replaced with a more anterior consonant excluding velar fronting and palatal fronting	Deleted	• Other fronting includes different categories that were separated into: 1. Articulation shifts: which included fricative simplification and lisping 2. Gliding: gliding (rabbit = /wæbɪt/) is counted twice in the CASALA program under Other fronting and Gliding. To avoid overestimation of gliding, gliding was not counted as Other fronting • No previous studies included *Other fronting*	• Fricative simplification: thumb = /fʌm/ (Dodd et al.2002) • Lisping: house = /haʊθ/ (Ball & Kent, 1997; Hodson, 1980)
2	*Cluster error:* A consonant in a cluster has been replaced with different consonant	1. Renamed: Cluster simplification: "…occurs when two elements of the cluster are produced, but one of both of the elements are produced in a non-adult manner" (p102, McLeod, Doorn, & Reed 2001b) 2. Excluded three words from cluster simplification as the CASALA program erroneously that considered them as clusters: a. toothbrush = /tu***θbr***ʌʃ/: treated as a three element cluster when it is a two element cluster b. biscuits = /bɪ***sk***ɪts/: /sk/ is not a cluster. If the child produced	• Based on previous studies, cluster simplification is known as one of the phonological processes that apply to consonant cluster production. The processes that affect singleton phoneme productions such as gliding, stopping and fronting are described as cluster simplification in the context of clusters. • Cluster simplification is well known to researchers and clinicians whereas the term cluster error is not mentioned in previous literature	• Cluster simplification: e.g., Three = fwi Spider = /θpaɪdə/ Swing = /fwɪŋ/, /twɪŋ/ Green = /bwin/ (Grunwell, 1987; McLeod, van Doorn, & Reed, 2001a; Smit,

		/bɪskɪts/ → /bɪθkɪt/, CASALA counts /θk/ as a cluster error which is incorrect count. /s/→ /θ/ substitution is counted a lisping in CASALA c. helicopter = /hɛlɪkɒ***pt***ə/: /pt/ is not a cluster. If the child produced /hɛlɪkɒ***pt***ə/ →/hɛlɪkɒ***kt***ə/, /***kt***/ was excluded from the cluster simplification count. /p/→ /k/ substitution was counted as backing and assimilation in CASALA		1993; Watson & Scukanec, 1997)
3	*Other backing and alveolar backing* * Other backing: A consonant is replaced with a more posterior consonant excluding alveolar backing * Alveolar backing: An alveolar consonant is replaced with a more posterior consonant	Renamed backing	• Alveolar backing and other backing were combined under backing (substitution of front and mid sounds with more posterior consonants)	• Other backing: /θæŋkju/→/sæŋkju/ • Alveolar backing: /noʊ**z**/ → /noʊ**ʃ**/ /sɒ**s**ɪʤ/ → /θɒ**ʃ**ɪʤ/ (Dodd et al., 2002)
4	Other diacritics:	Deleted, processes reassigned to other categories	• Other diacritics included different categories that were separated into:	

	A diacritic for which no process is enabled		1. Devoicing: the program did not recognize devoicing diacritic (e.g., /z̥/). CASALA recognized devoicing (substitution) on the phonemic level if the examiner used broad transcription (phoneme) rather than diacritics (e.g., /vaz/ → /vas/) 2. Dentalization: CASALA did not recognize the narrow transcription of dental /s̪/. CASALA recognized lisping if the examiner used broad transcription (phoneme /θ/) rather than using diacritics (e.g., /sɒk/ → /θɒk/). Dentalization and lisping articulation errors were combined in one category. 3. Nasalization was counted separately	• Devoicing: /vaz/ →/vaz̥/ (Bauman-Waengler, 2012) • Dentalization: /sɒk/ → /s̪ɒk/ (Bauman-Waengler, 2012)
5	Frication	Deleted	• Counted as cluster error (renamed simplification)	• Frication:/kwin/→/fwin/

Table 14. Summary of included phonological processes

Developmental Phonological processes	**Definition for each phonological process**	**Example**	Typical age of suppression
Cluster reduction	Reduction in the number of consonants in a cluster	spider = paɪdə elephant = eləfən	(6;0)*
Cluster simplification	A consonant in a cluster has been replaced with a different consonant	θri = fwi bread = bwed snake = θneɪk	(6;0)**
Weak syllable deletion	Deletion of unstressed syllable in a word	giraffe = waf umbrella = bwelə	(3;11)
Final consonant deletion	Deletion of the final signal consonant of a word	moon = mu	(3;3)
Stopping	A fricative or affricate consonant is stopped	sheep = tip	(3;5)
Gliding of liquids	A liquid is replaced with a glide	ring = wɪŋ	(5;11)
Devoicing	A voiced consonants is replaced with a voiceless consonant	vaz = zas	(3;0)
Voicing	A voiceless consonant is replaced with a voiced consonant	fish = bɪʃ	(2;11)

Deaffrication	An affricate consonant becomes a fricative consonant	cheese = ʃiz	(4;11)
Velar fronting	A velar consonant is replaced with an alveolar consonant	car = ta	(3;11)
Assimilation	A phoneme is replaced by another target phoneme in the same word		(3;0)
Non-developmental Phonological processes	**Definition for each phonological process**	**Example**	
Backing	Includes 1- Alveolar backing: An alveolar consonant is replaced with a more posterior consonant 2- Other backing: A consonant is replaced with a more posterior consonant excluding alveolar backing	thank you = /sæŋkju/	NA
Glottal replacement	Replacement of a consonant with a glottal stop		NA
Affrication	A non-affricate consonant is replaced with an affricate consonant	shoe = ʧu dog = zɒg	NA

Note. * Cluster reduction process suppresses by the age of 6 years. However, three cluster elements supress by 7+ (McLeod, van Doorn, & Reed, 2001a; Smit et al., 1990). ** Cluster simplification occur in sequence with cluster reduction (follow the same age of suppression rule)

Results

Development and non- developmental phonological processes in the speech of CWHL and CWNH

The presence of developmental and non-developmental phonological processes in the younger and older age groups was examined using two different criteria, firstly by considering processes that were present at least twice in at least two children in the group (lax criterion), and then processes that were present at least five times in at least two children in the group (strict criterion). For the younger CWNH aged 5;0-5;11 years, two processes were present: cluster simplification (40%; 30%) and gliding (20%; 20%) based on the lax and strict criteria (lax; strict). Ten percent of the older CWNH produced cluster reduction according to the lax criterion while no processes were present in the speech of CWNH when the strict criterion was applied. Non-developmental phonological processes did not occur in the speech of CWNH, as expected. A Chi-square test showed no statistical difference in developmental and non-developmental processes between age groups for the CWHL, χ^2 (2, N = 25) = 4.20, *p*=.122.

There was eleven developmental phonological process that had persisted in the speech of the CWHL. Figure 9 A-B illustrates the percentage of children produced developmental processes in two age groups based on the lax (A) and strict (B) criteria. There is an overall decrease in the percentage of phonological processes in the speech of older CWHL for both criteria. Figure 9 shows there is general consistency in the type of phonological processes that persist in the speech of younger and older CWHL. Figure 9 A. (lax criterion) shows that more than 50% of children in both age groups had cluster reduction, cluster simplification, stopping, and devoicing evident in their speech. It is expected that these processes will be supressed by the age of 4;11 in typically developing children. Gliding was present in more than 50% of the younger CWHL but it was present in less than 50% in older children based on the lax criterion. The literature indicates that gliding should be suppressed by the age of 5;0-5;11 years (Dodd, Alison Holm, Hua, & Crosbie, 2003). The remaining processes, velar fronting, assimilation, voicing, deaffrication, and final consonant deletion, were present in the speech of fewer than 40% of the CWHL.

Based on the strict criterion (Figure 9 B.) only cluster simplification and gliding were present for more than 50% of the younger CWHL. Although there was similarity in the percentage of children producing stopping and velar fronting across age groups based on the strict criteria, older children tended to devoice sounds more than younger children. Deaffrication and weak syllable deletion were not present in the speech of older age group when the strict criterion was applied. Weak syllable deletion was the least common process in the speech of the CWHL.

Figure 10 A-B shows the percentage of children who produced non-developmental processes in two age groups for the lax (A) and strict (B) criteria. Backing was less evident in the speech of older children however there was minimal difference between older and younger children for glottal replacement and affrication. Figure 10 B. shows that fewer than 20% of the children produced backing and glottal replacement based on the strict criterion. Affrication was the least common non-developmental process in the speech of CWHL and was not present when the strict criterion was applied. Overall, CWHL had a wide range of speech errors which were still evident in the speech of the school-aged children.

Development and non- developmental phonological processes in the speech of CIs and HAs users

A Chi-square test was performed and showed no difference in the occurrence of developmental and non-developmental processes between CI and HA children, χ^2 (2, N = 25) = 2.56, p=.277. There was a statistical trend for CI and HA children to differ for final consonant deletion χ^2 (2, N = 25) = 5.77, *p*=.056, with final consonant deletion more evident in children using HA devices.

Figure 11 A-B shows the percentage of CI and HA users who produced developmental phonological processes based on the lax (A) and strict (B) criteria. Figure 11 A. shows a general consistency in the type of phonological processes that persist in the speech of CI and HA users.

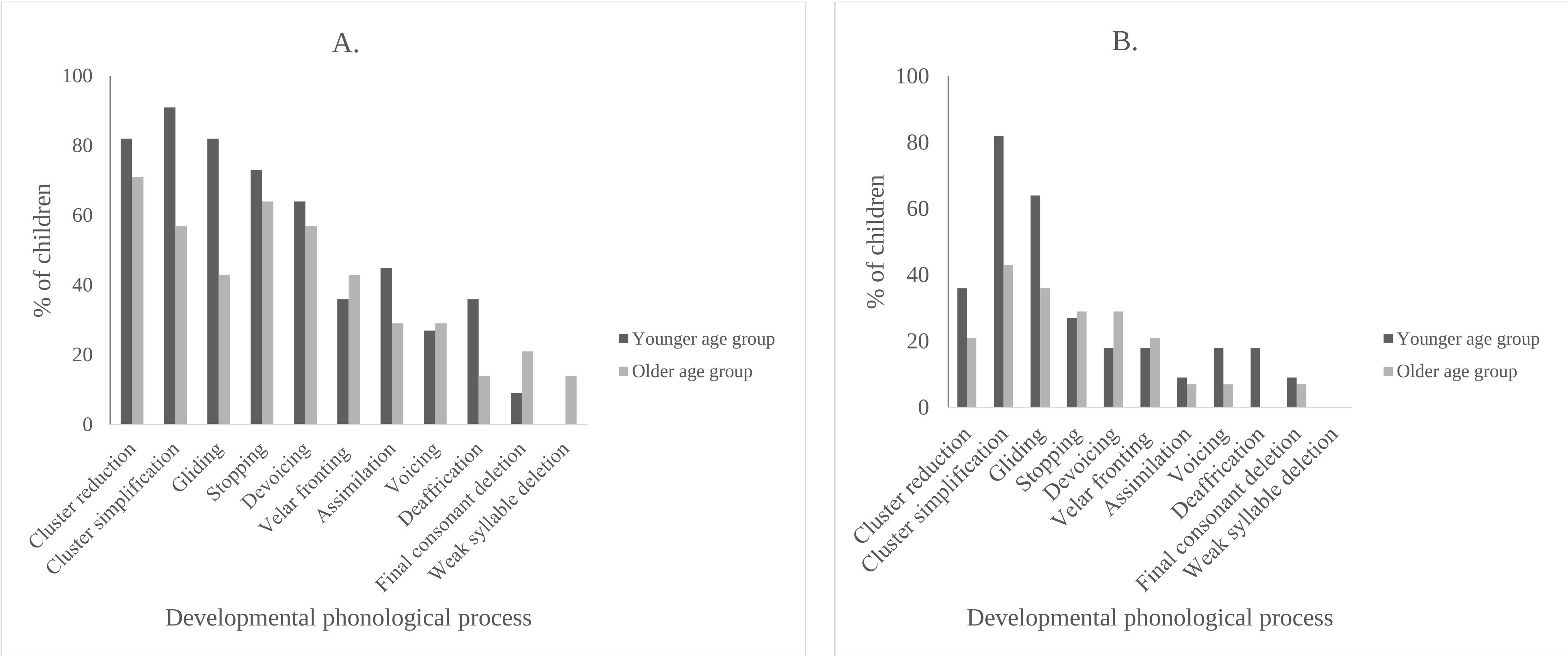


Figure 9. Percentage of children produced developmental phonological process in the younger (5;0-5;11, n=11) and older (6;0-7;5; n=14) based on A. lax and B. strict criteria

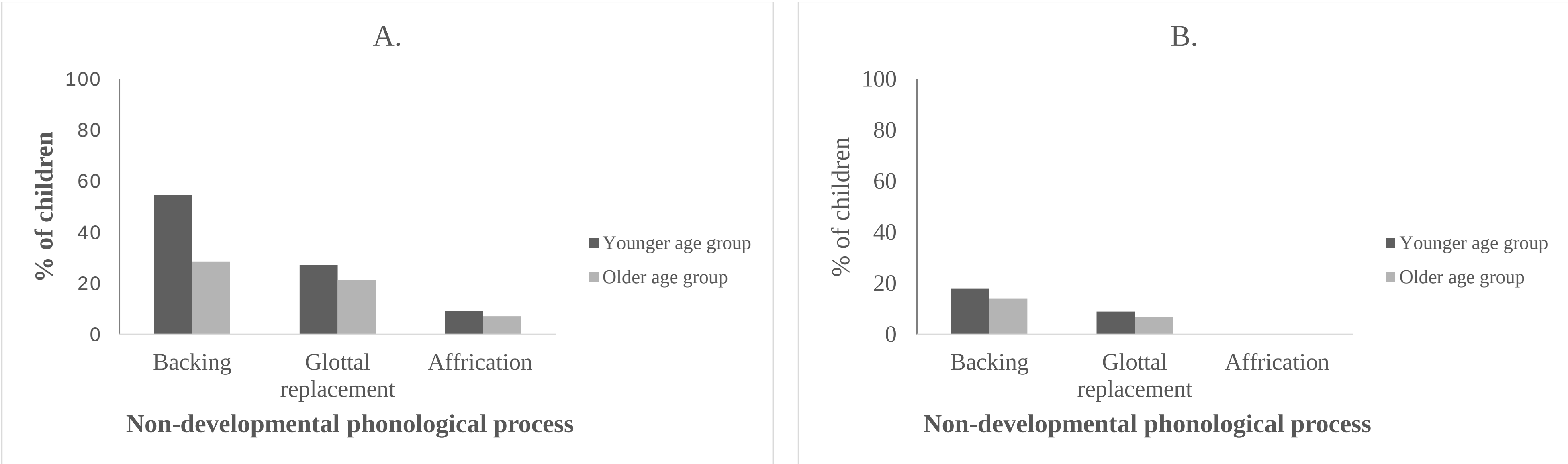


Figure 10. Percentage of children produced non-developmental phonological process in the younger (5;0-5;11, n=11) and older (6;0-7;5; n=14) age groups based on A. lax and B. strict criteria

More than 50% of CI and HA users had cluster reduction, cluster simplification, gliding, stopping and devoicing processes. These processes were evident in the speech of the school-age children. Cluster reduction, stopping, and devoicing processes occurred almost 10% more in the speech of CI users than HA users when the lax criterion was applied. CI users used more stopping and gliding processes than HA users. Figure 11 B. (Strict criterion) shows that only cluster simplification and gliding were present for more than 50% of CI and HA users. Devoicing, velar fronting, assimilation, and voicing were similarly present in the speech of CI and HA users (≤ 20%). Final consonant deletion and weak syllable deletion were not present in the speech of CI users based on the lax criterion; for the strict criterion deaffrication, and final consonant and weak syllable deletion were absent. Weak syllable deletion was the least common process in the speech of HA and CI users and was not present when the strict criterion is applied.

Figure 12 A-B shows the percentage of CI and HA children who produced non-developmental processes based on the lax (A) and strict (B) criteria. Figure 12 A. illustrates that 50% of the HA users and 25% of CI users used backing. Backing decreased to 31% in HA users and 8% in CI users when the strict criteria (Figure 12 B.). Glottal replacement was not present in the speech of CI users when the strict criterion applied. Affrication is the least common non-developmental process in the speech of CWHL using both HA and CI devices and was not present when the strict criterion is applied. Overall, non-developmental processes were more present in the speech of HA users than CI when the strict criterion was applied.

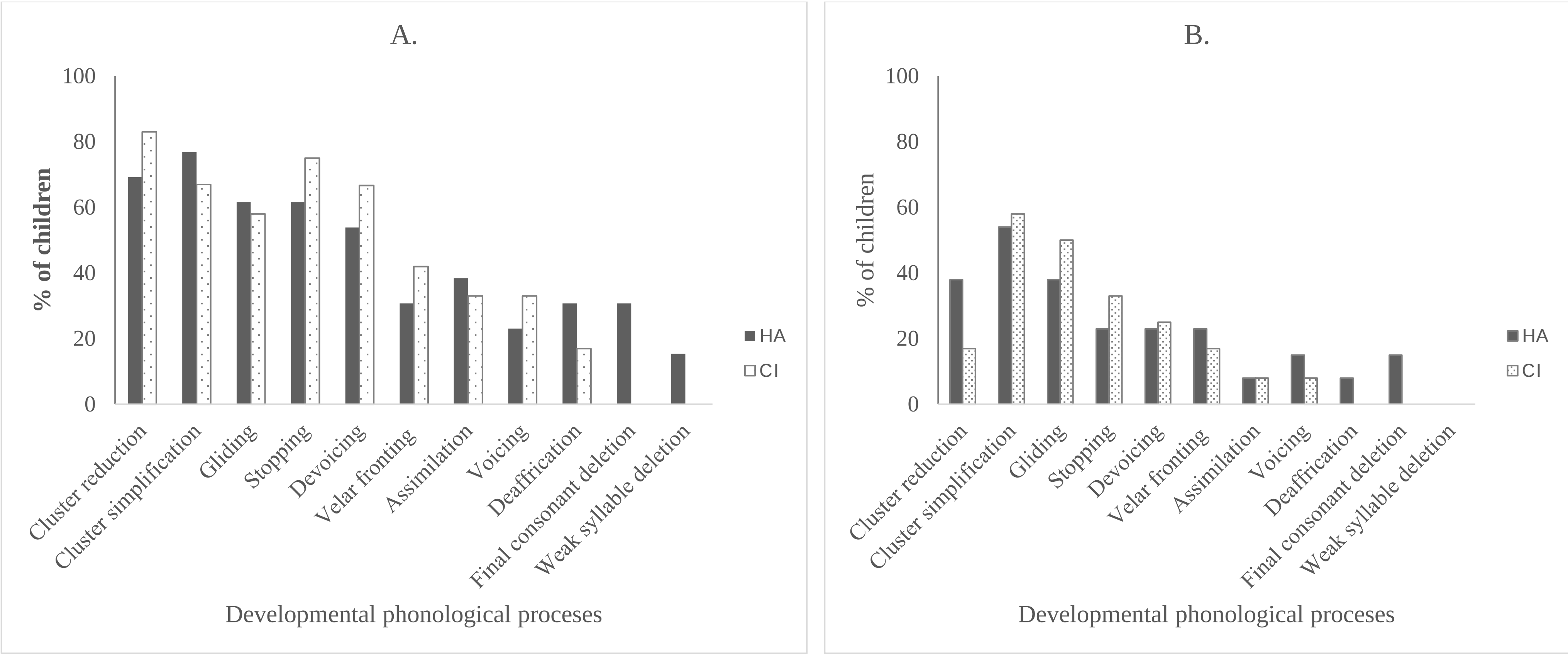


Figure 11. Developmental phonological processes in the speech of children fitted with CIs (n=12) and HAs (n=13) based on A. lax and B. strict criteria

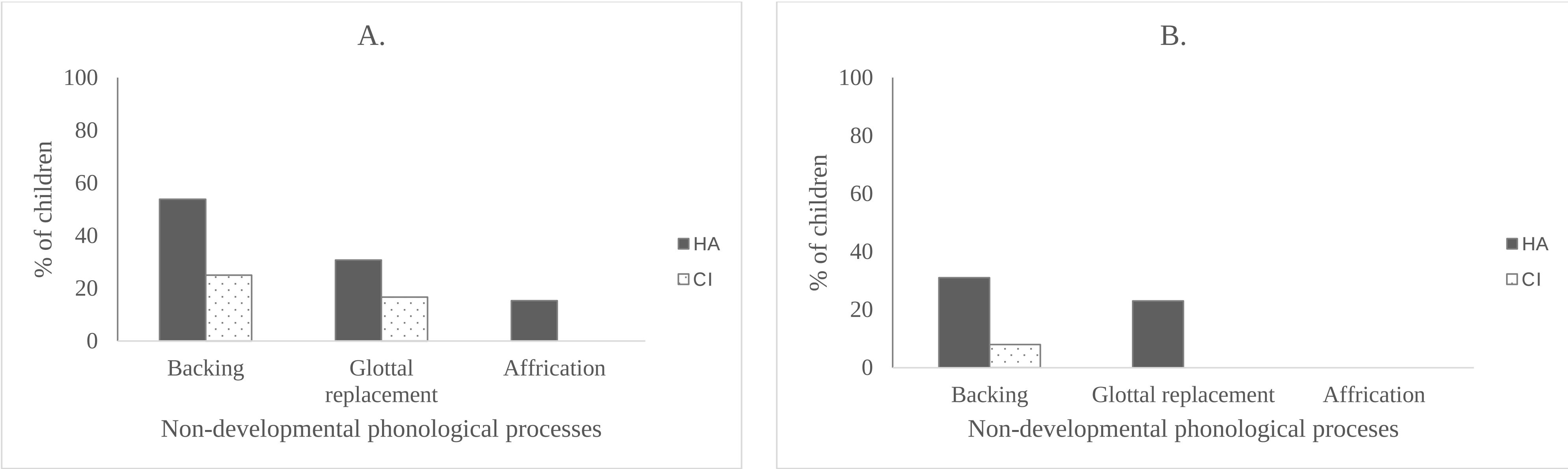


Figure 12. Non- developmental phonological processes in the speech of children fitted with CIs (n=12) and HAs (n=13) based on A. lax and B. strict criteria

Discussion

Few studies have investigated phonological processes that affect speech intelligibility that persist in children with mild-severe HL in comparison to children with profound HL who have been fitted with CIs. The aims of the current study were to compare developmental and non-developmental processes in the speech of school-age children with mild-to-profound HL to findings for typically developing children, and to compare phonological processes in the speech of CWHL using HAs and CIs based on lax and strict criteria.

Developmental and non-developmental phonological processes in the speech of CWHL and CWNH

Developmental phonological processes of CWNH were similar to those reported in previous studies which found that almost all processes were supressed by the age of five years (Bowen, 2015; Dodd et al., 2003). Cluster simplification and gliding were present in ≤ 40% of the younger CWNH. These processes are considered within the norms for typically developing children and are expected to be supressed by the age of 6 years (Dodd et al., 2003). Only 10% of the older children with normal hearing had cluster reduction. This was especially evident for the three-element cluster (in the word strawberry) based on the lax criterion. This agrees with Smit et al. (1990) who reported that typically developing children continue to acquire three-cluster elements up to 8;0 years. Similarly, James (2001) found that cluster reduction persists in 7-year-old CWNH (*N*=50), especially for polysyllabic words. No developmental processes were present when the strict criterion was applied to the CWNH. Non-developmental processes did not occur in the speech of school-age CWNH, as documented in previous studies. The differences between CWHL and CWNH were distinctive with considerably more developmental and non-developmental processes observed in CWHL, consistent with previous studies (Buhler et al., 2007; Eriks-Brophy et al., 2013; Flipsen & Parker, 2008; Huttunen, 2001).

Younger and older CWHL had 11 phonological processes: cluster reduction, cluster simplification, gliding, stopping, devoicing, velar fronting, assimilation, voicing, deaffrication, final consonant deletion, and weak syllable deletion. There was no significant difference in the type of developmental and non-developmental phonological process across age groups for CWHL. However, younger children tended to use cluster reduction, cluster simplification, and gliding more than older CWHL when both lax and strict criteria were applied (Figure 9). This is a cross-sectional study of a heterogeneous group of children and hence this finding needs to be interpreted with caution. The data from the current study suggest that the use of phonological processes may decrease overtime as CWHL gain hearing experience along with rehabilitation therapy program, however longitudinal studies examining changes over times in the same group of children are needed to confirm this. Consistent with the current study, Eriks-Brophy et al. (2013) found that 5-year old CWHL had fewer processes than 4-year old CWHL.

Cluster simplification and gliding were observed in the younger CWNH which suggests that some developmental processes are expected for CWHL but the frequency of use of these processes was higher in CWHL. CWHL demonstrated a similar trend of age of suppression of developmental processed to CWNH but at a slower rate, which is consistent with previous studies (Eriks-Brophy et al., 2013; Flipsen & Parker, 2008). Processes that are typically suppressed early such as assimilation, voicing, deaffrication, final consonant deletion, and weak syllable deletion were the least used processes for the CWHL (Figure 9). It is probable that the CWHL had used these processes at an earlier stage, but they had reduced by the time of testing.

CWHL in both age groups demonstrated atypical development processes. Backing and glottal replacement were the most common processes across age groups. Non-developmental processes occurred less often than was reported by Flipsen and Parker (2008) which could reflect methodological or sample differences. Non-developmental processes persisted until age seven years in the current study. In contrast, Eriks-Brophy et al. (2013) reported that non-developmental processes were supressed by the age of five in CWHL. This difference may be due to the CWHL in the study by Eriks-Brophy et al. (2013) being all early diagnosed and fitted with HAs and/or CIs and having more hearing experience than children in the current study. It is noteworthy that the occurrence of backing and glottal replacement in the CWHL in the current study had a severe impact on their speech intelligibility, which would likely lead to communication breakdowns between the CWHL and their classmates and teachers.

Development and non-developmental phonological processes in the speech of CWHL using CIs and HAs

We examined whether there was a difference between CI and HA users and found no significant difference in the processes produced by CI and HA children. Eriks-Brophy et al. (2013) similarly found no difference between CI and HA children in processes based on the KLP-2 assessment. Although the current findings are consistent with previous studies, the present study provides more detail on the types of process across age groups for HA and CI users. Cluster reduction, cluster simplification, gliding, and stopping processes were evident in the speech of both CI and HA children based on the lax criterion, which is consistent with previous studies (Law & So, 2006; Paatsch et al., 2001; Van Lierde et al., 2005). Cluster simplification and gliding were the most used processes by both HA and CI users based on the strict criterion. Thus, children using different hearing technology with various degrees of HL have phonological systems that resemble those of CWNH. Children fitted with CI tended to devoice final consonants rather than deleting them which resulted in a trend for higher use of devoicing than was evident in the HA users (especially for the lax criterion). Moeller et al. (2010) observed that stopping is one of the most common processes in children with mild-moderate HL. Flipsen and Parker (2008) also found that stopping was one of the most common processes in CI users. This also agrees with Eriks-Brophy et al. (2013) who found that stopping was prevalent in five year old children fitted with CIs and/or HAs. The prevalence of stopping in HA and CI users may reflect their limited access to high frequency sounds (with hearing aids due to limitations in high frequency amplification, and pre-implantation). This highlights the need for ongoing speech therapy for CWHL and the need to stimulate fricatives and affricates at pre-school age.

Eriks-Brophy et al. (2013), Paatsch et al. (2001) and Van Lierde et al. (2005) showed that CI children used final consonant deletion while none of the CI users in the current study did. Deaffrication, final consonant deletion, and weak syllable deletion were used by HA users only based on the strict criterion. The presence of these processes in HA users might be related to several factors: 1) the bandwidth of current HAs might be inadequate to accurately represent sounds of speech especially high frequencies; 2) smaller phonemic inventory and lower percentage of consonants correct (see Chapter 3); and 3) HA users received less therapy services than CI users in the current study.

Children who were fitted with HAs in the current study would be less intelligible to unfamiliar listeners than CI children due to prevalence of cluster reduction, final consonant deletion, weak syllable deletion, backing, and glottal replacement. This agrees with Hodson and Paden (1981) who investigated the phonological system of intelligible (n=60; aged 4 years) and unintelligible (n=60; aged 3;0-8;0) children. They found that specific processes such as final consonant deletion, weak syllable deletion, voicing, backing and glottal replacement occurred only in the speech of unintelligible children. Hodson and Paden (1981) noted that speech intelligibility is not only affected by the amount of phonological processes in the child's speech but also with the type of processes. SLPs need to be aware of the types of processes that persist in the speech of school-age children beyond the typical age of suppression and the processes that have the greatest effect on speech intelligibility in order to implement evidence-based, effective speech therapy for CWHL at preschool-age.

A limitation of the current study is the use of single words rather than connected speech assessment. Previous studies of children with speech sound disorder and CWHL show that children make more speech errors on connected speech samples than single word tests (Dubois & Bernthal, 1978; Ertmer, 2010). Ertmer (2010) found that children with mild-to-profound HL using HAs and CIs (N=44; age 2-15 year) had poorer speech intelligibility scores for connected speech samples than for single words (Goldman & Fristoe, 2000), as judged by inexperienced listeners. Ertmer (2010) noted that CWHL might produce words with deliberate focus on single words tests due to their speech intervention program; these typically start at the single word level before reaching sentence and generalization level (Hodson & Paden, 1986; Van Riper, 1978). Therefore, SLPs need be cautions when considering phonological processes in the speech of CWHL based on standardized tests alone. From a clinical point of view, SLPs are advised to combine child's standardized measures with connected speech measures, and to assess children's speech intelligibility to have a better, more holistic representation of a child's speech problem.

Conclusions

Children with mild to profound HL who used HAs and CIs demonstrated greater use of phonological processes than age-matched CWNH. Both developmental and non-developmental processes were observed in the speech of CWHL. The use of non-developmental processes reflects an inability to master the rules governing phonology (linguistic deficit) for CWHL, which would potentially affect their reading and writing abilities at school and hence warrants further investigation. Early supressed phonological processes were produced less than late supressed ones by CWHL which suggests that CWHL have similar phonological developmental abilities to CWNH but they progress at a slower rate. The presence of final consonant deletion, weak syllable deletion, glottal replacements and backing may affect the speech intelligibility of HA users more than CI users. Further research is needed to compare the speech intelligibility of CI and HA users rated by experienced and inexperienced listeners. In the current study, HA users received less intensive intervention than CI children which may be associated with smaller phonetic and phonemic inventories, (see Chapters 2 and 3) and less mature phonological skills than CI users. Because of the small sample and variations in age at detection and intervention it is difficult to draw such conclusions from the current study. Other variables that are likely to play a role in the development of phonological skills of CWHL include age at identification and intervention, amount of hearing experience, accuracy of device fitting, amount of device use, the appropriateness of the amplification for HA users, the access to speech sounds provided by the CI map for CI users, and the quantity and quality of therapy.

The current study will inform clinical practice by demonstrating the type of processes that persist in the speech of HA and CI (before the establishment of UNHS in NZ) in comparison to their peers, and by highlighting the processes that are used less by older CWHL and those that are likely to need speech therapy. Phonological processes that affect speech intelligibility were identified and the findings highlight the need to stimulate fricatives and affricates in pre-school aged CWHL and the importance of providing ongoing speech therapy to CWHL using HAs.

Appendix A

Word List used to determine the Children's Phonetic Inventory

No.	Target	Test	No.	Target	Test	No.	Target	Test	No.	Target	Test
1	Bird	DA	23	teeth	DP	45	ˈfeather	DP	67	witch	DC
2	Door	DA	24	watch	DP	46	ˈmonkey	DP	68	dinosaur	DC
3	car	DA	25	ˈorange	DP	47	ˈtoothbrush	DP	69	flower	H3
4	girl	DA	26	school	DP	48	ˈapple	DP	70	fork	H3
5	moon	DA	27	crab	DP	49	knife	DP	71	glove	H3
6	fish	DA	28	ˈbiscuits	DP	50	van	DP	72	gum	H3
7	thumb	DA	29	thank you	DP	51	ear	DP	73	page	H3
8	sock	DA	30	ˈhelicopter	DP	52	this	DP	74	plane	H3
9	chair	DA	31	egg	DP	53	ˈscissors	DP	75	slide	H3
10	jam	DA	32	splash	DP	54	ˈlighthouse	DP	76	smoke	H3
11	ring	DA	33	square	DP	55	ˈzebra	DP	77	star	H3
12	house	DA	34	pig	DP	56	ˈkitchen	DP	78	string	H3

13	foot	DA	35	queen	DP	57	ˈsausage	DP	79	vase	H3
14	ˈtelevision	DA	36	three	DP	58	ˈtiger	DP	80	zip	H3
15	ˈelephant	DP	37	frog	DP	59	ˈrabbit	DP	81	ˈcrayons	H3
16	umˈbrella	DP	38	ˈyellow	DP	60	book	DP	82	green	H3
17	train	DP	39	ˈstrawberry	DP	61	boy	DP	83	nose	H3
18	swing	DP	40	ˈspider	DP	62	shark	DC	84	mouth	H3
19	bread	DP	41	web	DP	63	boat	DC	85	cup	GF2
20	duck	DP	42	sheep	DP	64	jump	DC	86	drum	GF2
21	giˈraffe	DP	43	snake	DP	65	bridge	DC	87	blue	GF2
22	five	DP	44	pram	DP	66	chips	DC	88	clown	GF2

Note. Words are from: a) DEAP Articulation (DA) (14 words), b) DEAP Phonology (DP) (47 words), c) DEAP Consistency (DC) (7 words), d) HAPP-3 (H3) (16 words), and e) GFTA-2 (GF2) (4 words) tests.
(ˈ) stress position for multi-syllabic word

Appendix B

Phonological Processes for La Trobe

Abbreviation	Name	Description
ABA	Alveolar backing	An alveolar consonant is replaced with a more posterior consonant
AFF	Affrication	A non-affricate consonant is replaced with an affricate consonant
AS	Assimilation	A phoneme is replaced by another target phoneme in the same word
CD	Cluster deletion	Deletion of an entire cluster in a word
CE	Cluster error	A consonant in a cluster has been replaced with a different consonant
CI	Consonant insertion	Insertion of an additional consonant in a word
CR	Cluster reduction	Reduction in the number of consonants in a cluster
DAF	Deaffrication	An affricate consonant becomes a fricative consonant
DIP	Diphthongization	A monophthong is replaced by a diphthong
DNA	Denasalisation	(Phonemic) A nasal consonant is replaced with an oral consonant
DVO	Devoicing	(Phonemic) A voiced consonant is replaced with a voiceless consonant
ELO	Elongation	(Phonemic) A short monophthong is replaced with a long monophthong
FDE	Final consonant deletion	Deletion of the final single consonant of a word
FRC	Frication	A non-affricate, non-fricative consonant is replaced with a fricative
GIN	Glottal insertion	A glottal stop is inserted in a word
GLF	Gliding of fricatives	A fricative is replaced with a glide
GLL	Gliding of liquids	A liquid is replaced with a glide
GRP	Glottal replacement	Replacement of a consonant with a glottal stop
IDE	Initial consonant deletion	Deletion of the initial single consonant of a word
LIS	Lisping	(Phonemic) An /s/ becomes /th/ or /z/ becomes /dh/.
ME	Metathesis	Two phonemes within a word are swapped. Both are correctly produced
MI	Migration	Movement of a phoneme to a new position in the same word
MON	Monophthongization	A diphthong is replaced by a monophthong
NAS	Nasalisation	(Phonemic) An oral consonant is replaced with a nasal consonant
OBA	Other backing	A consonant is replaced with a more posterior consonant excluding ABA
ODE	Other consonant deletion	Deletion of a single consonant. Complement of FDE &/or IDE if enabled

OFR	Other fronting	A consonant is replaced with a more anterior consonant excluding VFR and PFR
OK	Correct	Result phoneme matches target phoneme
OST	Overstressed	Schwa is replaced with another vowel
PFR	Palatal fronting	A palatal consonant is replaced with an alveolar consonant.
RE	Reduplication	A word is replaced by two or more identical syllables
SD	Syllable deletion	Deletion of a syllable in a word
SHO	Shortening	(Phonemic) A long monophthong is replaced with a short monophthong
SI	Syllable insertion	Insertion of a syllable in a word. (Frequently schwa insertion; Epenthesis)
STF	Stopping of fricatives	A fricative or affricate consonant is stopped
STL	Stopping of liquids	A liquid is stopped
SU	Substitution	Phonemic or diacritic change not covered by any enabled phonological process
UN	Unintelligible	Unintelligible word or babble. No target word was available for transcription
VFR	Velar fronting	A velar consonant is replaced with an alveolar consonant
VOI	Voicing	(Phonemic) A voiceless consonant is replaced with a voiced consonant
VRD	Vowel reduction	A vowel (excluding schwa) is replaced with schwa
WDE	Weak syllable deletion	Deletion of an unstressed syllable in a word
elo	Elongation	Elongation diacritic
odi	Other diacritic	A diacritic for which no process is enabled
sho	Shortening	Shortening diacritic

Chapter 5: Differences in ratings of speech intelligibility and communication for children with hearing loss for parents *versus* teachers and experienced *versus* inexperienced listeners

Asad, A., Purdy, S. C., Ballard, E., Fairgray, L., Bowen, C., Demuth, K., & Sharma, M. (In preparation). Differences in ratings of speech intelligibility and communication for children with hearing loss for parents versus teachers and experienced versus inexperienced listeners.

This publication is inserted as it will be submitted for publication, with the exception of minor edits and formatting changes to maintain consistency throughout the thesis.

Abstract

Objective: In this study we investigated how the speech-intelligibility of children with hearing loss (CWHL) and children with normal hearing (CWNH) is rated by adult listeners with differing levels of familiarity with a child's speech characteristics.

Method: In Experiment 1 parents and teachers of 24 CWHL aged 5-7 who were using either hearing aids (HAs) (*n*=13) or cochlear implants (CIs) (*n*=11) completed a questionnaire about the children's communication abilities and rated their speech intelligibility on a 6-point scale. Experiment 2 participants were the 24 CWHL and age-matched controls (*N*=24) recorded re-telling a story and producing words from the Diagnostic Evaluation of Articulation and Phonology (DEAP). Thirty inexperienced and 22 experienced listeners rated the story-retell speech samples. Correlation analysis was conducted to compare percentage consonants correct (PCC) and percentage vowels correct (PVC) and intelligibility ratings.

Results: Although they rated intelligibility similarly, parents perceived that their CWHL were making greater progress with their speech than did teachers. Meanwhile, parents, teachers, and experienced listeners rated speech intelligibility of CWHL better than inexperienced listeners. Speech intelligibility ratings and speech accuracy were correlated. Hearing device-use (HA vs CI) is a somewhat arbitrary factor, and may be less relevant for examining speech intelligibility outcomes than continuous-type variables such as severity of HL or age at identification of HL, however, a trend for better ratings of speech intelligibility for children using CIs was observed.

Conclusion: It is helpful in clinical contexts to consider the perceptions of parents and other listeners who are familiar with a child's speech, and the perceptions of less familiar listeners such as teachers, and naïve listeners when evaluating the intelligibility of CWHL.

Keywords: cochlear implant, hearing aid, speech intelligibility, rating scale, percentage consonants correct

Introduction

Speech outcomes of children with hearing loss (CWHL) have been described at a phonemic level in terms of elimination of phonological processes, at a phonetic level in terms of articulatory proficiency, and at a listener-perception level in terms of speech intelligibility (Blamey, Barry, et al., 2001; Flipsen, 2011; Flipsen & Parker, 2008; Yoshinaga-Itano & Sedey, 1998). Speech "intelligibility" is defined as the degree to which a listener understands a speaker-delivered message. The present study is unique in that it is concerned with how rater-characteristics impact intelligibility ratings for CWHL, in early primary school, when the raters vary from parents, to teachers, to "other" experienced listeners, to naïve listeners.

Factors Impacting Speech Intelligibility

At least three factors affect speech intelligibility-rating outcomes: first, linguistic variables; second, speaker variables; and third, and most importantly for this investigation, rater variables, particularly the rater's experience with the individual whose speech is being rated. The literature associated with these three is examined briefly below, first noting that a fourth variable might include rater experience of actually rating, as opposed to their experience of the speaker *per se*.

1. Linguistic variables

Speech intelligibility may be influenced by the complexity of the language sample, which can be single-words (Chin, Finnegan, & Chung, 2001; Ertmer, 2010), sentences (Chin et al., 2003; Peng et al., 2004), conversational speech samples (Flipsen and Colvard, 2006; Lagerberg et al. 2014) and story-retell (Allen, Nikolopoulos, & O'Donoghue, 1998; Flipsen, 2006; Flipsen & Colvard, 2006; Flipsen & Parker, 2008; Tye-Murray & Spencer, 1995). By contrast, at least two studies have not relied on language samples but rather on reports of listeners' daily interactions with the speaker (Baudonck et al., 2010; Markides, 1986).

For the current study we used narrative language samples to investigate the children's intelligibility. This was done in the expectation that our findings would thereby be more relevant to classroom interactions, than they would have been with, say single-word or sentence sampling.

We also used scaling procedure, following Peng, Spencer, and Tomblin (2004) and Beltyukova, Stone, & Ellis (2008). Peng, *et al.* found that intelligibility measured using item identification and scaling approaches was highly correlated (r=.91, p<.001) for experienced CI users aged 9-18 years. Similarly, Beltyukova, *et al.* (2008) found that item identification and intelligibility rating using magnitude estimation yielded the same ranking of speech intelligibility in children with severe-to-profound hearing loss.

2. Speaker variables

Differences in speech intelligibility across CWHL relate to factors such as severity of HL, chronological age, age at identification, age at implantation, socioeconomic status, consistency and duration of hearing device use, and communication mode (Blamey, Sarant, et al., 2001; Crowe & McLeod, 2014; Ertmer, 2008; Habib, Waltzman, Tajudeen, & Svirsky, 2010; Jensema et al., 1978; Osberger, 1992; Peng et al., 2004; Svirsky & Chin, 2000; Svirsky, Chin, & Jester, 2007; Tobey, Geers, Sundarrajan, & Lane, 2011). Observing a population of children who were not receiving speech therapy intervention, Markides (1970) reported that those who consistently used HAs had significantly better speech intelligibility than those who did not.

Investigating 147 1-5 year-old children with mild to profound hearing loss, Yoshinaga-Itano and Sedey (1998) found associations between speech intelligibility and the child's age, degree of HL, language ability, and communication modality. Children with mild-moderate HL using only oral language had higher intelligibility ratings than children with significant HL. These findings were echoed in Tobey et al. (2003) who found that children in auditory-oral school environments had better overall speech production. Similarly, Connor, Hieber, Arts, and Zwolan (2000) who found a statistical trend for higher intelligibility scores in those using oral communication only compared with Total Communication.

3. Rater variables

The literature on raters reveals that most studies include few participants. In them, 'experienced' raters are typically caregivers, teachers of the deaf, SLPs, and audiologists in schools for the deaf (Inscoe, 1999; Monsen, 1983), and there is consensus that experienced listeners understand the speech of CWHL more readily than inexperienced listeners. Notably, Klimacka, Patterson, and Patterson (2001) compared the performance of six experienced SLPs who had worked with CWHL for 1-10 years, with the performance of six inexperienced listeners who were 2nd year SLP students. Using an orthographic procedure they measured the intelligibility of a nine year-old fitted with a CI. The six experienced listeners, unknown to the child were able to interpret the speech of the child more accurately than the six inexperienced listeners. This finding was consistent with Osberger's (1992) who reported that the intelligibility of CWHL is not reliant upon a listener's personal knowledge of the speaker in question.

Chin et al. (2003) compared speech intelligibility of CWHL (N=51) aged 2;8 to 10;8 (years;months), and children with normal hearing (CWNH) (N=47) aged 2;6 to 6;9. CWHL received cochlear implants (CIs) between 1;5 and 5;10 with an average duration of device experience of 2;4 years. The mean sentence level intelligibility score judged by inexperienced (unfamiliar with the speech of CWHL) listeners for the CI group was quite low (34.5%) and varied widely (0-98%). Mean intelligibility scores of CWNH were better on average, increasing from 54% for 2 year olds to 95% for 4 year olds. Thus, speech intelligibility does improve with CI experience but factors contributing to the wide variability across children need further investigation.

Among the few studies that have examined caregivers' perceptions of speech intelligibility in CWHL is Baudonck et al. (2010). They investigated how much caregivers and two experienced listeners (SLPs) understood of the everyday speech of CWHL. Children with CIs were rated as more intelligible by the SLPs than they were by their caregivers, signalling the possibility that SLPs, specifically, may over-estimate levels of speech intelligibility in CWHL whom they know.

To recap, researchers are in general agreement that intelligibility improves after cochlear implantation and is better with longer usage of hearing devices. CWHL are less intelligible than CWNH, and intelligibility outcomes vary widely across children with the same degree of HL and may be influenced by hearing technology (Chin et al., 2003; Ertmer, 2008; Flipsen & Parker, 2008; Geers, Brenner, & Tobey, 2011; Peng et al., 2004; Tye-Murray & Spencer, 1995). There are still a number of gaps in the literature, however, and few studies have measured different raters' perceptions of the speech of individual CWHL.

The Current Study

The focus of the current study is the impact of the characteristics of a person rating a child's speech. Intelligibility ratings of inexperienced and experienced listeners are compared in order to address the following questions:

1) Does listener familiarity with a child affect ratings of intelligibility of CWHL and children with normal hearing (CWNH)?

2) Do intelligibility ratings differ between children using HAs and those using CIs?

3) Are speech intelligibility ratings correlated with articulatory proficiency, as measured by the Diagnostic Evaluation of Articulation and Phonology (DEAP) (Dodd et al., 2002)?

Two experiments were undertaken. In Experiment 1, parents and teachers rated how much they understood of the child's speech during daily interactions using a 6-point scale (Yoshinaga-Itano & Allison Sedey, 1998).

In Experiment 1, all the raters were familiar with CWHL in general and the CWHL participants in particular. Parents and teachers based their ratings on *all* of their verbal communication experiences with the child.

In Experiment 2, inexperienced and experienced listeners, unfamiliar with the child participants, rated the intelligibility of CWHL and CWNH. The experienced listeners in Experiment 2 were not familiar with the children, but had prior experience communicating with CWHL. All the Experiment 2 raters based their ratings on listening to a single recorded story told by each child, rather than everyday interactions.

This study was approved by The University of Auckland Human Participants' Ethics Committee.

Method

Child Participants in Experiments 1 and 2

Participants in Experiments 1 and 2 were a heterogeneous sample of children aged 5-7 with mild to profound hearing loss (*N*=24) and children with normal hearing (*N*=24). Children were recruited from across the country and were tested in multiple locations. All but three of the CWHL were diagnosed with HL before newborn hearing screening began in New Zealand. Two were diagnosed with the beginning of newborn hearing screening in NZ and one child was diagnosed in the United States and grew up in New Zealand. The CWHL had: a) no diagnosed impairments other than deafness, b) typical cognition, with or without speech and language delay, c) been fitted with HAs or CIs, d) used spoken language rather than sign communication as predominant mode of communication, and e) spoken New Zealand English at home (but could be bilingual). The child's most recent audiogram was obtained from the audiologist. Table 15 lists the demographic characteristics of CWHL and CWNH. The socioeconomic status (SES) of all participants was based on the Ministry of Education spectrum of school decile rankings (Table 15). School decile is based on five weighted demographic variables (income, occupation, household crowding, education, income support) obtained from census data (Ministry of Education, 2008). There are three main categories for SES: low (deciles 1-3), middle (deciles 4-7), and high (deciles 8-10). Children in the two groups had a similar SES range.

Table 16 contains background information on gender, age at testing, age of identification, hearing level, communication mode, sensory aids, and duration of rehabilitation services of CI and HA subgroups. On average, CWHL had used at least one hearing instrument for 40 months (*SD* 23, range 1-78), and had unaided three frequency average (500, 1000, 2000 Hz) hearing thresholds of 66 dB HL in their better ear (*SD* 33, range 5-107) and 80 dB HL in their poorer ear (*SD* 24, range 32-115). The 11 children with one or two CIs had a minimum of 25 months CI use. Length of CI experience ranged from 25 to 64 months (*M* 45, *SD* 12). Three bimodal device users were grouped with the other CI users for analysis. In this manuscript, HA means "uses HAs exclusively" while CI means "uses at least one CI".

Data from a control group of 24 typically developing CWNH (Table 15) were examined in Experiment 2. CWNH were recruited from several New Zealand schools and were included if they met the inclusionary criteria: no diagnosed congenital or neurological impairments, no history of speech or language disorder, normal hearing based on distortion product otoacoustic emissions (DPOAE) measured using a Biologic Scout OAE screening device, English spoken at home. All control group children passed the DPOAE hearing screen at four frequencies or more (signal to noise ratio ≥ 6 dB).

The primary investigator who is a speech language pathologist (SLP) assessed the children's speech using a single word test, the DEAP (Dodd et al., 2002). Children's responses to the single word test were orthographically transcribed, and analyzed using a computer software package, CASALA (Computer Aided Speech and Language Analysis; Serry et al. 1997). For individual CWNH percentage of consonants correct scores (PCC) ranged from 78 to 100% (*M* 96 %, *SD* 6%). Percentage vowels correct (PVC) ranged from 99 to 100% (*M* 99.9%, *SD* 0.3%). All control children were within the norms of speech development. For the CWHL PCC ranged from 34 to 100% (*M* 79%, *SD* 17%); PVC scores were better but also varied widely from 67% to 100% (*M* 96%, *SD* 8%).

Experiment 1

Parent and Teacher Participants

Twenty-four parents (22 mothers, 2 fathers) of CWHL and 24 female classroom teachers employed in mainstream primary schools participated. Parents' education varied from high school to postgraduate. A questionnaire regarding the child's communication ability and speech intelligibility was sent to parents and teachers of each child with hearing loss.

Table 15. Demographic characteristics of children in the two groups (CWHL = children with hearing loss; CWNH = children with normal hearing)

	Age		Gender		School decile				Language background	
Part.	Mean (*SD*)	Range	Boys (*n*)	Girls (*n*)	1-3 (*n*/%)	4-7 (*n*/%)	8010 (*n*/%)	Median decile	English only (*n*)	Others (*n*)
CWHL	6.2 (0.7)	5.2-7.5	11	13	*n*=7 (29%)	*n*=6 (25%)	*n*=11 (45%)	7	18	6
CWNH	6.3 (0.7)	5.2-7.4	8	16	*n*=4 (17%)	*n*=6 (25%)	*n*=14 (58%)	8	18	6

Table 16. Hearing History, Hearing Instrument and Duration of Services of CI and HA Groups

Child	Gender	Age at testing (years)	Age of identifica tion (months)	Unaided thresholds R ear	Unaided thresholds L ear	Sensory aid	Age of first HA fitting (months)	Age of first CI fitting (months)	Communic. mode (months)	Duration habilitat. services (months)	PCC (%)	PVC (%)
P1	M	5.3	2	97	27	R: BAHA	24	_	Oral	36	70	100
P2	F	5.7	68	5	63	L: HA	67	_	Oral	_	79	100
P3	M	5.5	1	10	72	L: BAHA	65	_	Oral	_	96	100
P4	F	6.8	66	52	18	R: HA	75	_	Oral	_	100	100
P5	F	6.3	54	19	33	L: HA*	72	_	Oral	1	87	94
P6	F	6.3	18	55	47	Bilat HA	18	_	Oral	42	80	100
P7	M	5.5	30	65	60	Bilat HA	42	_	Oral	17	75	99
P8	M	5.5	30	62	63	Bilat HA	42	_	Oral	17	51	95
P9	M	7.5	41	87	83	Bilat HA	43	_	Oral + NZSL	49	68	96
P10	F	6.8	36	55	53	Bilat HA	48	_	Oral	34	34	67
P11	F	5.2	8	75	70	Bilat HA	10	_	Oral	50	88	100
P12	F	7.1	48	58	60	Bilat HA	60	_	Oral + NZSL	25	75	91
P13	M	5.9	48	32	28	Bilat HA	54	_	Oral	23	88	100
P14	F	6.8	24	100	93	R: CI	27	42	Oral	54	97	100
P15	F	6.6	25	92	93	R:HA;L: CI	24	54	Oral	54	90	100
P16	M	6.9	35	107	108	Bilat CI	_	36	Oral	46	77	96
P17	M	5.8	16	100	100	Bilat CI	17	21	Oral	47	82	100
P18	M	6.1	17	100	100	Bilat CI	17	20	Oral	54	96	100
P19	M	6.8	1	100	100	Bilat CI	4	23	Oral	54	99	99
P20	F	7.3	0	100	100	R: CI	3	12	Oral + NZSL	70	70	99
P21	F	5.6	18	83	115	R:HA; L: CI	18	24	Oral	43	54	78

P22	F	6.8	7	105	105	R: CI; L:HA	12	30	Oral	58	90	100
P23	M	6.2	24	106	90	R: CI	20	48	Oral	32	71	100
P24	F	5.2	16	77	87	Bilat CI	16	20	Oral	46	82	97
Mean			26.4	72.6	73.7		33.8	30.0		40.8	78.8	95.8
(*SD*)			20.0	31.5	28.5		22.8	13.3		17.0	16.8	8.3

Note. N = number; CI = cochlear implant; HA = hearing aid; NZSL = New Zealand sign language. L= left; R= right; Soft-band bone anchored hearing aid (BAHA)

Questionnaire

The questionnaire was developed based on clinical observation, discussion with SLPs and teachers working with CWHL, and parental input regarding the child's interactions with parents, teachers and friends in a range of speech contexts. The draft was sent to two parents of CWHL and three SLPs working with CWHL and children with speech sound disorders and was modified according to SLPs', parents' and teachers' feedback.

The final version of the questionnaire consisted of seven multiple-choice items (Appendix). Parents and teachers rated the child's speech intelligibility (Question 7) based on their daily life interactions with the child using a 6 point scale adapted from Yoshinaga-Itano and Sedey (1998) (1=I almost always understand the child's speech, 2=I almost always understand, however, I need to listen carefully, 3=I typically understand 50% of the child's speech, 4=I typically understand 25% of the child's speech, 5= the child's speech is very hard to understand. I typically understand only occasional, isolated words and/or phrases, 6=I never understand the child's speech). The original scale descriptors were modified slightly based on feedback during a piloting phase with parents and SLPs.

Procedure

Experiment 1 investigated the communication abilities and intelligibility of children with mild to profound hearing loss from the parents' and teachers' perspectives. Parents and teachers received a request to participate in the 'Speech outcomes of children with hearing loss' study. The main caregiver (usually the mother) and classroom teachers (who worked with the child with hearing loss for at least three months) completed the same questionnaire regarding the child's communication and rating speech intelligibility. Each parent and each teacher rated the same child. The first investigator followed-up the questionnaire completion process via email and telephone. The follow-up process to ensure questionnaires were completed took two to eight months with parents, as many sent incomplete questionnaires and some changed their phone number or place of living. For teachers, the follow-up process took two to twelve months as teachers reported that they were overloaded with school work.

Data Analysis

Kolmogorov-Smirnov tests indicated the data were not normally distributed and hence nonparametric statistical analyses were performed (IBM SPSS Statistics, version 21). Parents' and teachers' ratings were compared using Wilcoxon signed-rank tests.

Experiment 1 Results

Parents' and Teachers' Perceptions of Communication Abilities of CWHL

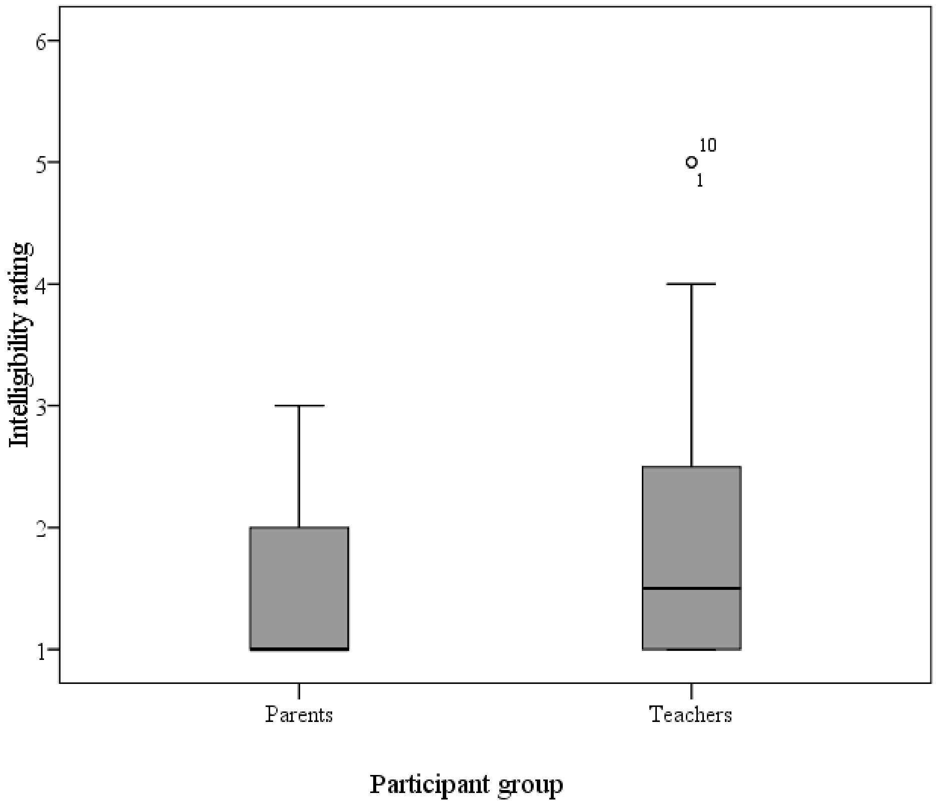
Based on parents' greater familiarity with their child we predicted that parents and teachers would evaluate the child's communication abilities differently. Wilcoxon matched-pairs signed-rank tests showed no significant differences between parents' and teachers' responses for the first five questions ($z = -1.89$, $p \geq .059$). The median rating for both groups was 2.0 for all five questions (M=.77, SD=1.63), indicating occasional communication problems. Only question 6 (Have you noticed an improvement in your child's speech in the last six months) showed a significant difference ($p = .012$) between groups. Table 17 shows that the teacher mean rank was 2.75 (3=a little improvement), while the mean rank for parents was 2.17 (2=noticeable improvement). Thus, parents reported greater improvement than teachers.

Table 17. Descriptive Statistics for Parents' and Teachers' Ratings for Questions 1- 6

Group	Mean	Std. Deviation	Minimum	Maximum	Percentiles		
					25th	50th (Median)	75th
Parents Q1	1.62	0.76	1	4	1	1.5	2
Teachers Q1	1.95	0.99	1	4	1	2	2
Parents Q2	2.08	1.05	1	4	1	2	2.7
Teachers Q2	2.00	0.97	1	5	1	2	2
Parents Q3	2.25	1.11	1	5	1.2	2	3
Teachers Q3	2.50	1.28	1	5	2	2	3
Parents Q4	2.04	1.26	1	5	1	2	2
Teachers Q4	2.00	1.14	1	5	1	2	2
Parents Q5	2.00	1.17	1	4	1	2	2.7
Teachers Q5	2.25	1.15	1	4	1	2	3
Parents Q6	2.16	1.16	1	4	1	2	3
Teachers Q6	2.75	0.89	1	4	2	3	3

Parents' and Teachers' Ratings of Speech Intelligibility for CWHL

We predicted that parents would rate their children as more intelligible than teachers, however the Wilcoxon signed ranks test showed no statistical difference (z = -1.90, p = .058) between teachers and parents for Question 7 (using the 6-point scale). Thus, parents and teachers rated their understanding of the child's speech similarly in their everyday communication environment. Figure 13 shows that there was a greater spread in teachers' ratings of speech intelligibility. On average children were rated as '2', indicating that parents and teachers almost always understood the child's speech; however they needed to listen carefully. Participants 1 and 10 are outliers based on the teacher ratings. Participant 1 has bilateral hearing loss with a mild loss in his better ear, and profound hearing loss in the worse ear, was early-identified and fitted with a soft-band bone anchored hearing aid (BAHA) at the age of 2 years. His PCC score (70%) indicates a moderate speech problem. Participant 10 who has moderate hearing loss and wears bilateral hearing aids, was late-identified and fitted with hearing aids at age 4 years. Her PCC and PVC scores were very low, at 33% and 67% respectively.



Note. The solid line in the box is the median rating for the group; the box indicates the 25th to the 75th percentiles. Outliers are indicated by circles (more than 1.5 box lengths from the upper edge) and the asterisk shows an extreme value (more than 3 box lengths from the box edge).

Figure 13. Parents' and Teachers' Ratings of Speech Intelligibility for CWHL

Experiment 2

Experienced and Inexperienced Listener Participants

Experienced and inexperienced participants rated the speech intelligibility of recorded connected speech samples from CWHL and CWNH. Experienced listeners, defined as people who had day-to-day interactions with CWHL, were recruited through advertisement to local clinics and Ministry of Education offices. Experienced listeners (*N* = 22, females) included pediatric audiologists (*n* = 3, *M* experience 5.7 years; *SD* 2.5), SLPs (*n* = 10, *M* experience 9.4 years; *SD* 6.8), an auditory verbal therapist (AVT, experience 24 years), advisors on the deaf (AOD) (*n* = 5, *M* experience 13.4 years; *SD* 10.6), and resource teachers of the deaf (RTD) (*n* = 3, *M* experience 9.3 years; *SD* 0.6) who had been working with CWHL for at least three years. The age of the experienced listeners ranged from 25 to 60 years (*M* 41; *SD* 13) and working experience ranged from 3 to 32 years (*M* 11; *SD* 8).

Inexperienced listeners (*N*=30, 70% females) were defined as people with no prior experience of CWHL or who had occasionally heard the speech of a person with HL but not on a daily basis. The age of inexperienced listeners ranged from 18 to 34 (*M* 23; *SD* 4). These listeners were younger on average than the experienced listeners, however a Spearman correlation revealed no statistically significant relationship between intelligibility ratings and listener age ($p = .569$). Inexperienced listeners were all students recruited via electronic mail and flyers posted to University of Auckland faculties.

Listeners in both groups reported normal hearing and were native speakers of English or bilingual speakers living in New Zealand by the age of 10 years. Education level varied from Bachelors to PhD.

Connected Speech Sample

The story-retell stimulus ‘The shipwreck story’ from the Test of Narrative Language was used (Gillam & Pearson, 2004). This story was chosen as, typically: 1) children are able to narrate a story based on five sequenced pictures by the age of five; 2) children can relate the story to their daily activities (e.g. going to school); 3) the sentence structure varies in this story from simple to complex. The sample was audio-recorded in order to determine how much listeners understood of the child’s overall speech, not to examine language structure or narrative abilities. To elicit the speech sample CWHL and CWNH first listened to the recorded story ‘The shipwreck story’ narrated by a native English speaker while looking at five sequenced pictures that correspond with each event in the story. The child then retold the story while looking at the pictures. If the child had difficulty narrating the story, the first investigator used some general prompts (e.g. Tell me what happened in this picture? Who is this? What happened after that?). Each participant’s speech sample was video- and audio-recorded in a quiet room at school, home or in the speech and hearing clinic at the University of Auckland.

A high-quality microphone (HC577L) placed 10 cm from the participant’s mouth was used for recordings, and was connected to a Dell LATITUDE laptop with Adobe Audition 5 software, M-Audio preamplifier, and Flip camera. Recordings were edited using Audacity (2.0.3) to remove examiner prompts. Sample durations were 36 to 88 seconds for CWNH (*M* 1:02 min:sec); and 26 to 157 seconds for CWHL (*M* 1:08 min:sec). Speech samples were organised so that experienced and inexperienced listeners (unaware of children’s hearing status) listened to randomized samples of CWHL (*N*=30 speech tracks, 24 from each child and 6 repeated tracks used to check reliability, interspersed amongst other tracks) and then to randomized speech samples of CWNH (*N*=30 tracks). The randomization was the same for all raters. A statistical comparison of ratings for the first 15 tracks compared to the second 15 tracks for the CWNH indicated no order effects. Mann Whitney U tests showed that mean and median ratings did not differ for the first versus last 15 tracks for inexperienced (U = 107, z = -.23, p = .819, r = -.041; U = 110, z = -.13, p = .900, r = -.023, respectively) or experienced listeners (U = 109, z = -.15, p = .883, r = -.027; U= 98, z = -1.44, p = .150, r = -.262 respectively).

Procedure

Experiment 2 compared the story-retell speech intelligibility of the CWHL to that of the control group of CWNH (N=24), and examined how much inexperienced listeners understood the speech of CWHL and CWNH in comparison to experienced listeners. A total of 52 normally hearing adult listeners (30 inexperienced, 22 experienced listeners) rated the speech intelligibility of the CWHL and CWNH using the same 6-point scale adapted from Yoshinaga-Itano and Sedey (1998) that the parents and teachers also used in Experiment 1. Raters attended one session for about one hour, twenty minutes, in a computer lab or quiet room. All listeners performed ratings of 60 randomised speech samples (listened first to 30 randomized samples for CWHL; then listened to 30 randomized samples for CWNH) audio-only at a comfortable loudness level via headphones (Panasonic RP-HT460) attached to a Dell desktop computer or LATITUDE laptop. Six children's recordings were repeated for each group to assess intra-rater reliability but listeners were told they would hear a story narrated by each child only once (without knowing whether recordings were of CWHL or normal hearing) and were instructed to rate how much they understood of the child's speech after listening to the whole sample. Listeners were informed that they needed to listen to the story and rate intelligibility without paying attention to language structure. Instructions included the following example: "If you worked in a supermarket and a child came in and told you something, you would focus on knowing what the child wants rather than thinking about the child's language structure. I want you to rate how much you understand from the child's story". The instructions were read and participants listened to two training speech samples and rated them before proceeding. This provided an opportunity for participants to set up a comfortable listening volume during the training. They were asked not to go back and change any responses on the answer sheets after making a rating. Listeners were paid for their participation unless this was not permitted by their employer.

Data Analysis

Overall intelligibility ratings for each child were calculated as the median rating of the panel of 30 inexperienced listeners and the median rating of the panel of 22 experienced listeners. Mann-Whitney U tests were used to compare ratings by experienced and inexperienced listeners for individual CWHL and CWNH. Ratings of parents/teachers and inexperienced and experienced listeners for individual CWHL were compared using Spearman correlations and Wilcoxon signed-rank tests. A significance level of 0.05 was used for all statistical comparisons. Inter-rater reliability was determined separately for experienced (N=22) and inexperienced (N=30) listeners using the Kappa Coefficient (Fleiss, 1971). Intra-rater reliability was determined by comparing ratings for 25% of samples for each group (6 CWNL, 6 CWHL) using Wilcoxon signed-rank tests. Mann-Whitney U tests were used to compare intelligibility ratings for CWHL using CIs versus HAs.

Experiment 2 Results

Intra and Inter-rater Reliability

There was acceptable intra-rater reliability among inexperienced and experienced listeners when ratings were compared for the same (randomized) speech samples using Wilcoxon signed-rank tests ($z = -1.89$, $p \geq .059$, indicating no test-retest differences). CWNH were assigned ratings of 1 to 3 by all listeners whereas ratings from 1 to 6 were assigned to the CWHL. Almost all CWNH (99% and 94%, respectively) were assigned the same rating of 1-2 by experienced and inexperienced listeners (Figure 14).

Fleiss's Kappa analyses were conducted to examine inter-rater agreement for experienced and inexperienced listeners rating the speech intelligibility of CWHL and CWNH. As different raters have a range of experiences in listening to the speech of children, high inter-rater reliability was not expected. There was fair agreement between experienced listeners in judging the speech intelligibility of CWHL, $\kappa = .325$ (95% CI, .301 to .343), and slight agreement in judging the speech intelligibility of CWNH $\kappa =.117$ (95% CI, .920 to .142). Thus, experienced listeners were more consistent in their ratings of speech of CWHL, which might be related to their work experience. There was slight agreement amongst inexperienced listeners' ratings of speech intelligibility of CWHL, $\kappa = .272$ (95% CI, .261to .283), and CWNH $\kappa =.104$ (95% CI, .091 to .120).

The relatively low inter-rater reliability, particularly for inexperienced listeners, suggests variability in individual listeners' experience affects judgements of intelligibility. Most of the variation across raters occurred as a result of the same child with normal hearing being assigned a rating of 1 or 2 by different listeners, and CWHL being assigned 5 or 6 by different listeners. Most raters assigned ratings of 1 or 2 to CWNH; any small degree of randomness or variability across raters in whether the children received a 1 or a 2 would have reduced inter-rater reliability.

Experienced versus Inexperienced Listeners

Mann-Whitney U tests were conducted on CWHL and CWNH in order to determine whether ratings differed between experienced (N=22) and inexperienced (N=30) listeners. For CWHL, eighteen of the twenty four children showed statically significant differences between the groups of listeners as shown in Table 18 (asterisk indicates all significant p values, less than or equal to .045). For the remaining 6 CWHL (P3, 4, 5, 13, 18, 19), ratings did not show significant differences for the two groups of listeners (p values all greater than or equal to .063), as shown in Table 18. For CWNH, thirteen of the twenty four showed statistically significant differences between the groups of listeners as shown in Table 19 (asterisk indicates all significant p values all less than or equal to .024). The remaining 11 CWNH (TD1, 2, 4, 5, 6, 7, 12, 15, 16, 17, 18), did not show a significant difference for the two groups of listeners (p values all greater than or equal to .071). The mean age of these 13 children (*M* 6.4, *SD* .58) did not differ from the 11 children (*M* 6.1, *SD* .73) for whom equivalent ratings were assigned by inexperienced and experienced listeners. Inexperienced listeners rated relatively more children as 2 (I almost always understand; however I need to listen carefully).

A Wilcoxon signed-rank test showed median ratings across the 24 CWHL were significantly better for the experienced (range 1-5) compared to the inexperienced (range 1-6) listeners ($z = -3.27$, $p = .001$). For the CWNH the Wilcoxon signed-rank test showed median ratings across the 24 CWHL were also significantly better for the experienced compared to the inexperienced listeners ($z = -2.64$, $p = .008$). Median ratings across listeners ranged from 1 to 2 for all CWNH for experienced and inexperienced listeners. For CWNH 99% of the ratings by experienced listeners were 1 or 2; for inexperienced listeners 94% of the ratings were 1 or 2.

Table 18. Experienced and inexperienced listeners' rating the speech intelligibility of each child with hearing loss

CWHL	Mann-Whitney U	*p*-value	*r*
P1	223	.024*	-0.312
P2	264	.027*	-0.306
P3	323	0.748	-0.044
P4	319	0.392	-0.117
P5	277	0.261	-0.155
P6	224	.007*	-0.41
P7	211	.015*	-0.337
P8	169	.002*	-0.429
P9	187	.004*	-0.4
P10	188	.002*	-0.427
P11	253	.016*	-0.334
P12	153	.000*	-0.492
P13	281	.296*	-0.144
P14	168	.001*	-0.464
P15	112	<.001*	-0.581
P16	204	.015*	-0.337
P17	210	.013*	-0.342
P18	271	.177	-0.157
P19	253	.063	-0.257
P20	233	.036*	-0.289
P21	177	.003*	-0.417
P22	234	.045*	-0.277
P23	192	.006*	-0.38
P24	178	.001*	-0.441

Note. * $p \leq .045$ (2-tailed), *r*=effect size

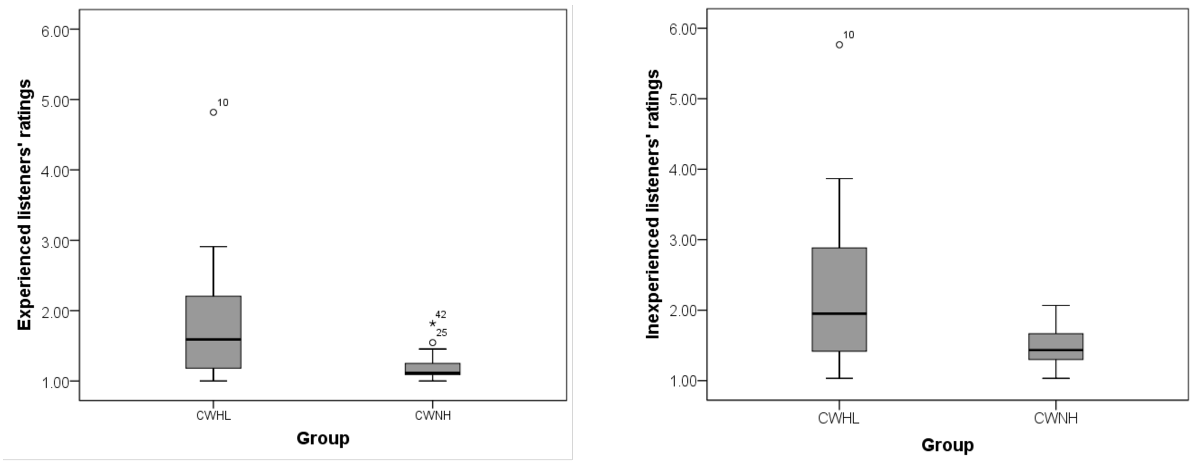
Table 19. Experienced and inexperienced listeners' rating the speech of each child with normal hearing

CWNH	Mann-Whitney U	*p*-value	*r*
TD1	241	.074	-0.246
TD2	282	.176	-0.187
TD3	232	.023*	-0.314
TD4	301	.293	-0.145
TD5	261	.071	-0.249
TD6	319	.392	-0.117
TD7	281	.167	-0.191
TD8	203	.010*	-0.357
TD9	225	.012*	-0.348
TD10	210	.007*	-0.373
TD11	231	.022*	-0.317
TD12	252	.098	-0.228
TD13	217	.008*	-0.368
TD14	238	.024*	-0.313
TD15	316	.639	-0.063
TD16	307	.596	-0.073
TD17	294	.286	-0.147
TD18	267	.197	-0.177
TD19	187	.002*	-0.418
TD20	235	.013*	-0.343
TD21	183	.002*	-0.434
TD22	228	.014*	-0.339
TD23	203	.010*	-0.356
TD24	214	.011*	-0.352

Note. * $p \leq .024$ (2-tailed), *r*=effect size

Intelligibility Ratings of CWHL versus CWNH

Ratings by inexperienced and experienced listeners were averaged for each participant in the two groups (CWHL and CWNH, *N*=48). Mann-Whitney U tests indicated group differences between CWHL and CWNH for inexperienced, *U* = 150, *z* = -2.86, *p* = .004, *r* = -.412, and experienced listeners, *U* = 152, z = -2.82, *p* = .005, *r* = -.406. CWNH had significantly better speech intelligibility ratings than CWHL. Figure 14 compares speech intelligibility ratings of CWHL and CWNH. As expected, the range of ratings was larger for CWHL than CWNH for both experienced and inexperienced listeners. Participant 10 with hearing loss and participants TD25 and TD42 with normal hearing are outliers. Participant TD25 is a monolingual English speaker with signing deaf parents. Participant TD42 is a monolingual English speaker but has a bilingual Mandarin/English mother.



Note. CWHL = children with hearing loss; CWNH = children with normal hearing. The solid line in the box is the median rating for the group; the box indicates the 25th to the 75th percentiles. Outliers are indicated by circles (more than 1.5 box lengths from the upper edge) and the asterisk shows an extreme value (more than 3 box lengths from the box edge)

Figure 14. Speech Intelligibility Ratings of CWHL and CWNH Averaged across Inexperienced (N=30) and Experienced (N=22) Listeners (Low ratings represent higher intelligibility, 1=always understand the child's speech; 6=I never understand the child's speech).

Experiments 1 & 2: Intelligibility Ratings of CWHL

Agreement between Experienced and Inexperienced Listeners and Parents/Teachers

In Experiment 1, each child's speech intelligibility is rated by two people parent/caregiver and a teacher; both raters are experienced with speech of CWHL and are familiar with this particular child. Additionally these two raters form their opinions from their entire life-time of experience with this child. In Experiment 2, each child's speech intelligibility is rated by 22 people experienced with CWHL (but unfamiliar with these particular children) and by 30 people who are inexperienced with CWHL (and, hence, also unfamiliar with these children). These 52 raters form their opinions of a child from 'an acute listening experience', namely a single story-retell from that child. Ratings for each child with hearing loss for the three groups of raters, inexperienced listeners, experienced listeners, and parents/teachers, were compared using Spearman correlations. There were significant correlations between the ratings of all three groups (Rs = .41, p =.031 to Rs = .98, $p < .001$) indicating agreement in the ranking of intelligibility of the CWHL even though ratings differed overall between groups. A Friedman non-parametric test for related samples showed significant differences in ratings across the three groups ($\chi(2) = 18.73$, $p < .001$). Wilcoxon tests investigating which pairs of raters differed showed that inexperienced listeners rated speech of CWHL differently from the other two groups ($z = -2.13$, $p \leq .033$). Experienced listeners and parents/teachers' ratings were similar ($p = .602$). This suggests that the different methods for obtaining the ratings yielded equivalent results for people experienced with listening to CWHL.

Speech Intelligibility Ratings of CI and HA Users

We investigated whether speech intelligibility ratings differed between children using HAs and those using CIs. Mann Whitney U tests indicated that intelligibility ratings of children with CI (n = 11) and HA users (n = 13) did not differ significantly for inexperienced listeners (U= 59, p = .469, r = -.147), experienced listeners (U= 64, p = .663, r = -.087), or parents/teachers (U= 58, p = .414, r = -.165). There was a difference in the distribution of ratings between HA and CI users. Figure 15 illustrates the ratings intelligibility summed across each group of raters for HAs and CIs. The range of ratings was wider for HA users than for CI users. None of the CI users was assigned a rating of 5 or 6 by any listener.

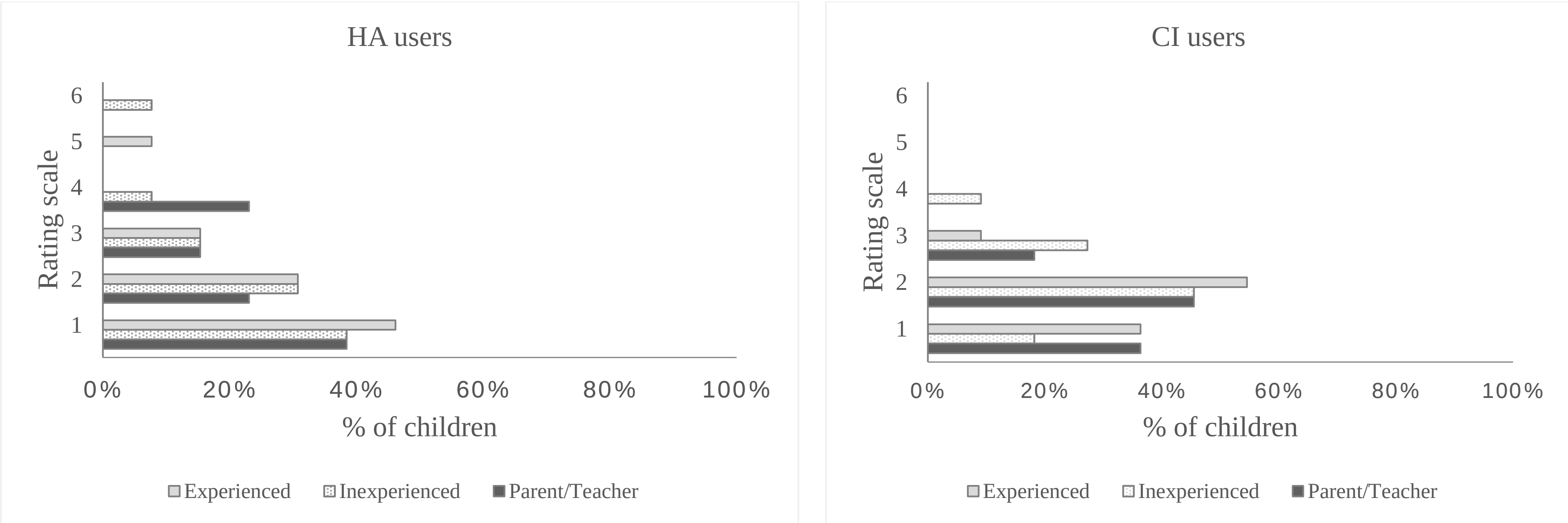


Figure 15. Distribution of Ratings of Intelligibility for Different Groups of Raters for CWHL Using HAs (n=13) or CIs (n=11).

Speech Accuracy, and Speech Intelligibility for CWHL

We investigated the association between speech accuracy (PCC, PVC) and intelligibility ratings by inexperienced and experienced listeners and parents/teachers. This comparison was conducted to test the validity of the speech intelligibility ratings. Spearman correlations showed that for all three groups of raters, speech intelligibility ratings correlated significantly with PCC (Rs = -.53 to -.84, $p \leq .008$) and PVC (Rs = -.54 to -.81, $p \leq .007$) (see scatter plots in Figure 16). Most (77%) of children fitted with HAs were rated between 1 and 2 and PCC was 70-96%; 91% of those fitted with CIs were rated between 1 and 2 and PCC showed a similar range of 70-99%.

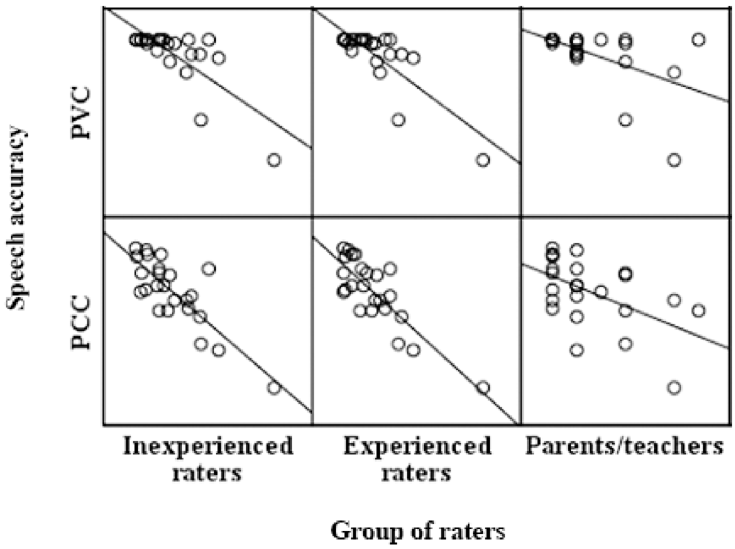


Figure 16. Correlations between Speech Accuracy (Percent Consonants Correct, PCC; Percent Vowels Correct, PVC) and Speech Intelligibility Ratings from Three Groups of Raters.

Discussion

The overall aim was to explore how different listeners judge the intelligibility of CWHL and CWNH. Two experiments were conducted investigating how the speech of CWHL was rated by different listeners, comparing CI and HA users, and examining the association between speech intelligibility and speech accuracy.

Parent and teacher perceptions of communication and intelligibility of CWHL

Parents and teachers had similar ratings of the communication abilities of CWHL based on five questions focusing on their direct interactions with the child. Few studies have looked previously at agreement between parents and teachers. Oberg and Lukomski (2011) found good agreement in ratings of emotional control and working memory by parents and teachers. To our knowledge no study has looked at the communication abilities of CWHL comparing parents' and teachers' perspectives.

Results from Table 17 indicate differences between parent and teacher judgements of the child's speech improvement over the previous six months. Parents reported noticeable improvement in their child's speech while teachers reported little improvement. This difference might have resulted from different internal criteria as parents may consider a small improvement as a big achievement in contrast to how the child's speech used to be. Teachers may base their scoring on the child's speech performance in class and may have noticed less change over time because classroom activities become more challenging over time. One teacher reported that she based her judgement on the child's improved ability to produce speech sounds in spelling and reading tasks.

Within the field, there is a lack of information regarding teacher's and parent's speech intelligibility ratings of CWHL. The present study investigated whether parents would rate their children as more intelligible than teachers, but there was no statistical difference between parents and teachers based on the survey ratings. Figure 13 shows that teachers had a wider range of ratings than parents. Teachers reported difficulty understanding the speech of participant 1 and 10. Both children had low speech accuracy and greater number of substitutions for one sound to another. In contrast to the current findings, Flipsen (1995) showed mothers were significantly better than school teachers in understanding the speech of children with speech sound disorder. Parents might be more familiar with the child's speech than teachers because parents have a greater contextual knowledge (e.g., knowing name of relatives, friends and general activities (Wilcox, Kouri, & Caswell, 1990).

Experienced versus Inexperienced Listeners

Consistent with earlier studies (Klimacka et al., 2001; McGarr, 1983; Monsen, 1983; Osberger, 1992), experienced listeners rated the speech of CWHL as more intelligible than inexperienced listeners. Experienced listeners may have the advantage of being familiar with children's speech, familiar with various linguistic backgrounds (such as the child's accent), and make use of contextual information (Osberger, 1992). It is possible that the ability of inexperienced listeners to understand the speech of CWHL was reduced whenever there was a mismatch between the listener and the speaker in terms of supra-segmental speech characteristics, dialect, and typical speech errors, in addition to the impact of HL (Markides, 1983).

There was a significant difference between experienced and inexperienced listeners in rating the speech of 13 out of 24 CWNH. The median ratings across inexperienced and experienced listeners for the speech intelligibility of CWNH ranged from 1 to 2. It is possible that there is a ceiling effect for the CWNH making it difficult to determine differences between experience and inexperienced listeners. The data show that inexperienced listeners gave the child a score of one if they were a monolingual speaker with no speech errors and a score of 2 whenever the child was a bilingual or monolingual speaker who spoke softly, or had substitution errors affecting fricatives and liquids. Thus, adult listeners in the inexperienced group (not previously exposed to speech of people with HL) found that they needed to listen carefully to understand a significant proportion of the speech of the normally hearing children. These listeners may have had limited interaction with children, and limited knowledge of children's speech.

Overall, the results highlight the important influence of listening experience and linguistic background in speech understanding, as demonstrated by McAuliffe and colleagues' (2010) in their investigation of dysarthric speech. We cannot conclude that it was only experience with CWHL that accounts for differences in intelligibility ratings. Group differences in intelligibility ratings might have resulted from raters having more experience with children's speech in general, or more experience in using scales to rate things, and/or use of contextual information, or being familiar with various dialects.

Intelligibility rating of CWHL and CWNH

Consistent with previous research (Baudonck et al., 2010; Chin et al., 2003; Montag, AuBuchon, Pisoni, & Kronenbergerb, 2014), CWNH had better speech intelligibility ratings than CWHL (Figure 14). The mean rating of experienced listeners for the speech intelligibility of CWNH was 1 except for two children (TD25, TD42). Although TD25 did not have speech errors this child tended to speak slowly and softly. TD42 had some speech errors in her speech sample such as dentalization. The difference between experienced and inexperienced raters for the two CWNH (TD25, TD42) evident in Figure 14 might be related to listeners' internal rating criteria (Ertmer, 2011). For example, one experienced listener reported that she assigned a score of '2' whenever she heard distorted speech because this child might have speech disorder especially if the error affected a sound that would normally have been acquired in typically developing children of the same age as the participant. Similarly, Lagerberg and colleagues (2014) noted that some SLPs who orthographically transcribed the speech samples were stricter than their colleagues and gave children the minimum intelligibility rating whenever they were not sure about the produced syllable.

P10, who had the poorest speech intelligibility overall, received the worst intelligibility rating by experienced and inexperienced raters and by his teacher (outlier in Figures 13 and 14). This is consistent with Sitler et al.'s (1983) finding that listeners were not able to use contextual cues to understand the speech of children with poor speech intelligibility. P10's poor speech intelligibility may have resulted from a combination of factors, as he was late-identified (3 years), fitted with HAs and received support a year later, lived in a bilingual environment with low socioeconomic status, used HAs inconsistently , and had speech errors (e.g., final consonant deletion, stopping of fricatives). This is consistent with previous studies (Khwaileh & Flipsen, 2010; Peng et al., 2004; Tye-Murray & Spencer, 1995) that showed an association between age of identification, severity of hearing loss, duration of hearing instrument use, and speech accuracy and intelligibility ratings.

The gap in speech intelligibility between CWHL and CWNH would lead to communication difficulties at home and school. Poor speech intelligibility may play a role on how well CWHL integrate at school and whether they will achieve good academic performance in comparison to their peers. This was evidence in the current study as one teacher of a child (P1) with hearing loss commented "The child started school with speech problems and it is very hard to understand the child's speech. Thus, placing barriers from the beginning in interacting with other".

Agreement between Experienced and Inexperienced Listeners and Parents/Teachers

Parents, teachers, and unfamiliar people communicate with CWHL in various communication settings and contexts. Baudonck et al. (2010) found that children with CIs were rated as more intelligible by the SLPs than they were by their parents. This suggests that SLPs may underestimate intelligibility difficulties associated with HL compared to other groups interacting with the child. Parents and teachers did not differ in the current study and judged speech intelligibility in the same way as experienced listeners; these groups rated intelligibility of CWHL higher than inexperienced listeners, due to their greater familiarity with the speech of CWHL.

Speech Intelligibility Ratings of CI and HAs Users

The present study investigated whether the intelligibility ratings differ between children using hearing aids and CIs users. There was no statistical difference in the speech intelligibility of CI and HA users in the current study. Although there was no statistical difference based on the Mann Whitney U test, Figure 15 shows that more children with CIs had good intelligibility ratings – none of the CIs users received a low rating of 5 or 6. This is consistent with Van Lierde et al. (2005) who found better speech intelligibility ratings in children using CIs than children with severe hearing loss using HAs.

In the current study we investigated a heterogeneous group of CWHL with hearing severity ranged from mild to severe hearing loss. The intelligibility of CWHL in the current study is higher than that of children in Yoshinaga-Itano and Sedey’s (1998) study using the same scale, which could be related to factors such as age of identification (about 50% of the children were late identified), advances in hearing technology, and length of hearing device experience. Parent/teacher ratings in the current study show that 61% of HAs users and 81% of CIs users were always understood or understood with careful listening (ratings of 1-2).

Similarly, Baudonck et al. (2010) found that 61% of the HA users were judged as intelligible while 69% of CI users were intelligible. Baudonck et al.'s participants were older (6-15 years), however their CI users had lower overall intelligibility than those in the current study. The age range at which participants received their CIs is similar in the two studies and hence differences in habilitation or etiology may account for this. It is difficult to draw conclusions, given the differences in study design.

Previous studies have found associations between speech intelligibility and age at implantation, degree of HL, language ability, and communication modality (Habib, Waltzman, Tajudeen, & Svirsky, 2010; Peng et al., 2004; Svirsky, Chin, & Jester, 2007; Yoshinaga-Itano & Allison Sedey, 1998). In the present study, the wider range of speech intelligibility ratings for HAs users might be related to several factors, including early age of fitting (mean for HAs 47.7 months and *SD* 20.7; mean for CIs 15.8 months and *SD* 7.7) and length of habilitation services (mean for HAs 26.7 months and *SD* 17.3; mean for CIs 50.7 and *SD* 9.7). Children fitted with CIs received habilitation services from the age of identification until the age of five through the New Zealand Northern and South Cochlear Implant Programs, and then received continuous support at school from a multidisciplinary team. Thus, CI users received ongoing consistent therapy services but there was variation in the amount, intensity and type of therapy across children who were fitted with HAs. For example, P1 whose PCC showed that he had a moderate speech problem was discharged from therapy services at the age of testing (5.3 years), despite his teacher finding it hard to understand his speech. She reported that "There appears to be very limited assistance for children with speech problem. The criteria for assistance seems to be for only very extreme cases".

Gordon-Brannan and Hodson (2000) recommended intervention for 4 year olds whose speech intelligibility scores are lower than 66% and that therapy should stop when the child is

90% intelligible. In the current study Figure 15 showed that about a third of the CWHL who were fitted with HAs had poor speech intelligibility (ratings of 3-6) based on experienced and inexperienced ratings. Unfortunately, the intervention programs of nine out of 13 children who were fitted with HAs (four children did not receive any therapy) did not include speech therapy. Further longitudinal research is needed to determine the speech development and speech intelligibility outcomes of HA users receiving ongoing therapy.

Speech Accuracy, and speech intelligibility for CWHL

There was a significant correlation between PCC, PVC, and inexperienced, experienced listeners' and parents/teachers' ratings of speech intelligibility. Ertmer (2010) also found a moderate correlation between PCC and intelligibility (r = .49, p < .001), and a weak correlation (r = .38, p < .05) between PVC and intelligibility. Across different degrees of HL, children with speech errors were less intelligible in the current study, particularly for inexperienced listeners, suggesting that these CWHL will face challenges in their daily communication if they interact with communication partners who do not know them well. An adaptation of the 6-point scale developed by Yoshinaga-Itano and Sedey (1998) was used in the current study. The correlations between speech intelligibility ratings and speech accuracy support the concurrent validity of the revised rating scale (Figure 16). The scale is easy to use and might be useful in clinical practice for measuring speech progress of CWHL, but this would require longitudinal data from CWHL.

Study Limitations

The principal limitation of this study is the relatively small number of CWHL and the heterogeneous nature of the group (use of technology, degree of HL, age at identification, etc.). Because of this heterogeneity it was difficult to identify specific factors contributing to intelligibility outcomes. Measuring speech intelligibility using a connected speech sample and speech accuracy measures (PCC and PVC) may not account for the lived experience of CWHL and people around them. For example, adults and CWNH might find it challenging to understand the speech of CWHL in noisy environments such as the playground.

Conclusions

This investigation demonstrates that familiarity with the speech of CWHL affects speech intelligibility ratings and differences in intelligibility ratings occur across listeners. The study highlights the use of speech intelligibility as a diagnostic outcome measure in CWHL, but the results may be applicable to other groups with speech difficulties. SLPs should be cautious in judging the speech intelligibility of CWHL based on their perception only. There was no significant difference between ratings of parents and teachers. SLPs need to be aware that parents and teachers have a different perceptive of the child's speech improvement over time. Parents reported noticeable improvement in their child's speech overtime while teachers reported little improvement. We advise SLPs to include speech intelligibility ratings from family members and teachers and others who are not experienced with the speech of CWHL. Importantly, the poor speech intelligibility of some CWHL, despite the use of hearing instruments, highlights the need for ongoing SLP monitoring of CWHL.

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Declaration of Interest Statement

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Chapter 6: Discussion and conclusions

This chapter summarizes the major findings of the four studies presented in this doctoral thesis, and discusses how the research aims were fulfilled. This is followed by a discussion of implications for clinical practice. Finally, the limitations of the study, and suggested future directions are discussed.

One of the most significant contributions of this thesis is that most of the children were later-identified and this cohort can serve as a comparison once early identification is a reality in New Zealand as the result of establishment of UNHS. The study is significant because it provides SLPs with a comprehensive speech profile of school-age children with mild-to-profound hearing loss. First, the current study forms a foundation for understanding the sounds that a child with HL can produce (phonetic inventory), the type of sounds that a child with HL can produce correctly in comparison to typical developing children (phonemic inventory), the types of phonological processes that may persist in their speech, and how much an unfamiliar listener may understand the speech of CWHL in comparison to their parents, teachers and clinicians (speech intelligibility). Second, the study explains the criteria for establishing a word list based on different standardized assessments (DEAP, GFTA-2 and HAPP-3) in order to evaluate the speech of CWHL. Third, few studies have previously examined the speech of children with mild-to-severe HL fitted with HAs; these children have recently been characterized as ‘Our Forgotten Children’ (Davis, 1990; Moeller & Tomblin, 2015). The current study addressed this gap and examined the speech profile of children who were fitted with HAs as well as children with CIs. One of the significant findings is that children with moderate-to-severe HL were at risk for SSD (and consequently for academic delays, although this was not examined here) which might be related to late age of identification, late age of fitting, and underestimation of the amount of rehabilitation/service support that they needed (Davis, 1990; Moeller & Tomblin, 2015). Fourth, CWHL had poorer speech intelligibility than CWNH which is likely to lead to communication difficulties at home and school. The speech profile outcomes of CWHL investigated in the current study will form the foundation for upcoming research on CWHL in NZ focussed on effective speech therapy approaches for CWHL. The current study informs clinical practice by demonstrating the types of processes that persist in the speech of HA and CI users in comparison to their age-peers with normal hearing, and highlights the processes that are used less by older CWHL and hence that are likely to have less need for speech therapy. An important implication of the data is the need to stimulate fricatives and affricates in pre-school aged CWHL and the importance of providing ongoing speech therapy to CWHL using HAs.

Summary

This thesis aimed to establish the speech profile of school-age children with mild-to-profound HL by examining their phonetic inventory, phonemic inventory, speech accuracy, phonological processes and speech intelligibility. Four cross-sectional studies were conducted to establish the speech profile of CWHL in comparison to their typically developing peers.

Chapter 1 provided overall information about hearing loss (HL), definitions of speech measures, phonetic inventory, phonemic inventory, phonological processes, speech intelligibility, and a discussion of the challenges of using available standardised speech assessments in assessing CWHL. The review of previous studies highlighted the lack of research providing comprehensive speech information for school-age CWHL and the lack of available research on the speech of children with mild-to-severe HL fitted with HAs, and the need for further research in this area (Moeller & Tomblin, 2015).

Chapter 2 described the phonetic inventory of early school-age children (aged 5;0-7;5 years) with a range of HL and compared younger (5;0-5;11) and older (6;0-7;5) children within the group. This chapter examined the phonetic inventory of CWHL using a word list based on three published assessments (DEAP, GFTA-2, HAPP-3). The phonetic inventory in onset and coda positions was compared. In addition, this study explored whether sound acquisition differed between CWHL using HAs versus those with one or more CIs. Results showed that CWHL produced fewer stops, fricatives, affricates, and liquids than CWNH in both younger and older age groups. In addition, there was a significant difference in the average number of vowels between CWHL and CWNH, but only for the older age group. The significant difference in vowel production for the older group might be related to other variables such as severity of HL, age of diagnosis and fitting, consistency of wearing hearing devices and the amount of ongoing therapy received. We were not able to examine these factors due to small sample size, and since this research relied on a convenience sample of children we were not able to control for these factors. Overall, the vowel phonetic inventory was better than consonants, which might be related to the bandwidth of the hearing devices allowing sufficient amplification of vowels and/or access to proprioceptive cues (Ling, 2002), but insufficient amplification of some consonants. CWHL acquired fewer sounds in coda than onset position, which is consistent with Abraham (1989). Speech delay in acquiring consonants in coda position in the CWHL might be related to sounds in coda position being less acoustically salient resulting in these sounds not being sufficiently audible for the CWHL despite their use of amplification. As expected, children with mild HL had better phonetic inventories in onset and coda position than children with moderate-to-severe HL and CI users. Children with moderate-severe HL had the smallest phonetic inventories as they had not acquired 14 sounds: [k, g, f, v, θ, ð, s, z, ʃ, ʒ, ʧ, ʤ, r, j] in onset and coda position, which is likely to affect their overall speech intelligibility. The results showed that children with moderate to severe hearing loss fitted with HAs were particularly at risk for not fully acquiring the linguistic system of English language, which could negatively affect overall academic achievement, particularly in the areas of reading, spelling and writing. This study provides good information regarding what children with various degrees of HL can produce at early school age.

Chapter 3 reported PCCs and PVCs of school-age CWHL in comparison to their peers, PCCs and PVCs in HA versus CI users, and the consonants produced accurately in onset and coda by children with varying degrees of HL. This study is significant as no previous study has examined phonemic accuracy in onset and coda position and speech accuracy in school-age children (aged 5;0-7;5) with hearing loss.

PVCs of CWHL were similar to CWNH in both age groups (5;0-5;11 and 6;0-7;6). Greater production proficiency for vowels in comparison to consonants by school-age supports the notion that vowels are acquired earlier in the speech of CWHL (Ambrose et al., 2014; Ertmer, 2001), resembling speech development in CWNH. Moreover, vowel accuracy was similar in HA and CI users. This suggests that vowels were more audible and the bandwidth in HA and CI users allowed them to access (hear and perceive) vowels. Consonant accuracy (PCC) of CI users was slightly better than HA users. Results also revealed that residual hearing played a role in speech acquisition (Ambrose et al., 2014; Tomblin et al., 2014; Yoshinaga-Itano & A. Sedey, 1998) as children with mild HL outperformed children with moderate-to-profound HL. Previous studies show that fricatives and affricates are the most common persisting errors in the speech of children with mild to moderate hearing loss (Elfenbein et al., 1994). Consistent with this the current study showed that a range of stops, fricatives, affricates, and liquid were produced with < 90% accuracy indicating persisting phonological processes and consequently poor speech intelligibility.

Chapter 4 reported developmental and non-developmental phonological processes that persist in the speech of school-age children with mild-to-profound HL in comparison to their peers. This study also examined phonological processes persisting in the speech of HA and CI users.

The results showed that the differences between CWHL and CWNH were distinctive with considerably more developmental and non-developmental processes were observed in CWHL, consistent with previous studies (Buhler et al., 2007; Eriks-Brophy et al., 2013; Flipsen & Parker, 2008; Huttunen, 2001). There was no significant difference in the type of developmental and non-developmental phonological process across age groups for CWHL. However, younger children tended to use cluster reduction, cluster simplification, and gliding more than older CWHL when both lax and strict criteria were applied. This was a cross-sectional study of a heterogeneous group of children and hence this finding needs to be interpreted with caution. The data from the current cross-sectional study suggest that the use of phonological processes may decrease over time as CWHL gain hearing experience alongside other therapy programs, however longitudinal studies examining changes over times in the same group of children are needed to confirm this. The results also revealed that non-developmental processes occurred less often than was reported by Flipsen and Parker (2008) which could reflect methodological or sample differences, or perhaps improvements in hearing technology giving better access to speech for CWHL.

Non-developmental processes persisted until age seven years in the current study. In contrast, Eriks-Brophy et al. (2013) reported that non-developmental processes were supressed by the age of five in their sample of CWHL. This difference may be due to the CWHL in the study by Eriks-Brophy et al. (2013) being early identified and fitted with HAs and/or CIs while there were very few early-identified children in the current study. Thus, children in Eriks-Brophy et al. (2013) study had more hearing experience than children in the current study.

There was no significant difference in the processes produced by CI and HA children. Although the current findings are consistent with previous studies (Eriks-Brophy et al., 2013), the present study provides more detail on the types of processes across age groups for HA and CI users. Deaffrication, final consonant deletion, and weak syllable deletion were used by HA users only, based on the strict criterion. The presence of these processes in HA users might be related to several factors: 1) the bandwidth of current HAs might be inadequate to accurately represent sounds of speech especially high frequencies; 2) smaller phonemic inventory and lower percentage of consonants correct (see Chapter 3) in this group; and 3) HA users may have received less therapy services than CI users in the current study, although this was not systematically investigated. It is very important for SLPs and audiologists to have more information about the speech perception abilities and the quality of the programming of the HAs and mapping of CIs in order for them to optimise speech production outcomes for CWHL.

Chapter 5 reported how the speech intelligibility of CWHL and CWNH is rated by adult listeners with differing levels of familiarity with the speech characteristics of CWHL. Parents perceived that their CWHL were making greater progress with their speech than did teachers. Consistent with earlier studies (Klimacka et al., 2001; McGarr, 1983; Monsen, 1983; Osberger, 1992), experienced listeners rated the speech of CWHL as more intelligible than inexperienced listeners. CWNH had better speech intelligibility ratings than CWHL which is consistent with previous findings (Baudonck et al., 2010; Chin et al., 2003; Montag, AuBuchon, Pisoni, & Kronenbergerb, 2014). Parents, teachers, and experienced listeners (SLPs) rated speech intelligibility of CWHL better than inexperienced listeners. There was no significant difference between parents, teachers and experienced listeners' (SLPs) ratings. Experienced listeners may have the advantage of being familiar with children's speech, familiar with various linguistic backgrounds (such as the child's accent), and may make more use of contextual information Osberger, (1992). Overall, the results highlighted the important influence of listening experience and linguistic background in speech understanding, as demonstrated by McAuliffe and colleagues' (2010) in their investigation of dysarthric speech. We cannot conclude that it was only experience with CWHL that accounts for differences in intelligibility ratings. Group differences in intelligibility ratings might have resulted from raters having more experience with children's speech in general, or more experience in using scales to rate perceptions, and/or use of contextual information, or being familiar with various dialects. Poor speech intelligibility may play a role on how well CWHL integrate at school and whether they will achieve good academic performance in comparison to their peers. There was no statistical difference in the speech intelligibility of CI and HA users, which might be related to small sample size, however, overall more children with CIs had good intelligibility ratings – none of the CIs users received a low rating of 5 or 6. The trend for better speech intelligibility ratings for CI users supports the earlier findings reported in Chapters 2 and 3 in which CI users had better phonetic inventory, phonemic inventory, and speech accuracy results than HA users in the current sample. This is consistent with Van Lierde et al. (2005) who found better speech intelligibility ratings in children using CIs than children with severe hearing loss using HAs. One third of the CWHL who were fitted with HAs had poor speech intelligibility (ratings of 3-6) based on experienced and inexperienced ratings. Unfortunately, the intervention programs of nine out of 13 children in the current study who were fitted with HAs (four children did not receive any therapy) did not include speech therapy. Further longitudinal research is needed to determine the speech development and speech intelligibility outcomes of HA users receiving ongoing therapy. Finally, SLPs rated the speech intelligibility of CWHL higher than inexperienced listeners, presumably due to their greater familiarity with the speech of CWHL.

Clinical implications

Auditory deprivation significantly affects the speech production of both infants and school-age CWHL (Ertmer & Goffman, 2011; Geers, Brenner, & Tobey, 2011; Geers, Moog, Biedenstein, Brenner, & Hayes, 2009; Nathani & Oller, 2008; Nathani et al., 2007). Moreover, the speech profile of CWHL varies based on degree of HL. The intensity of habilitation is likely to be another factor, but was not investigated here. The current study found that, despite the use of modern hearing technology, specific active intervention is still required to reduce delays in speech development for CWHL. Children with moderate to severe hearing loss using HAs were at particular risk in the current study. The production of velars, fricatives, and affricates may need to be specifically taught for CWHL, ideally before children commence school as speech delay may impact the emergence of reading, spelling and writing, with potentially significant consequences for all school learning (Yoshinaga-Itano, 2004). Children with moderate-to-severe HL need a comprehensive speech therapy program, and ideally clinicians need to stimulate less accurate phonemes at pre-school age rather than after children enter school and problems are more apparent Moeller & Tomblin, 2015). The current study informs clinical practice by demonstrating the types of processes that persist in the speech of HA and CI in comparison to their peers, and by highlighting the processes that are used less by older CWHL and those that are therefore less likely to need speech therapy. Phonological processes that affect speech intelligibility were identified. The findings highlight the need to stimulate fricatives and affricates in particular in pre-school aged CWHL and the importance of providing ongoing speech therapy to CWHL using HAs.

Finally, it is helpful in clinical contexts to consider the perceptions of parents and other listeners who are familiar with a child's speech, and the perceptions of less familiar listeners such as teachers, and naïve listeners when evaluating the intelligibility of CWHL. The intelligibility study highlighted that SLPs may underestimate intelligibility difficulties associated with HL compared to other groups with less familiarity with the speech of CWHL who are likely to be interacting with the child in their everyday life.

Limitations of study

The principal limitation of this study is the relatively small number of CWHL and the heterogeneous nature of the group (use of technology, degree of HL, age at identification, etc.). We were not able to to examine correlations between age of identification, age of hearing fitting, the length of therapy services and speech intelligibility because of the heterogeneity of CWHL. A larger sample size would allow regression analysis to look at the relative impact of these factors on speech outcomes. In addition, interpretation of the finding that children with mild HL had better phonetic inventories and better speech accuracy than children with moderate-to-profound HL is limited by the fact that there were only four participants with mild hearing loss. Hence it is difficult to generalize these findings, although they are consistent with other studies. Therefore, more children with a range of HL need to be evaluated over a longer time span in future studies. The strengths of the current study include the fact that we compared the speech profile of CWHL with age- and gender-matched peers with normal hearing and hence the delay in speech outcomes of the CWHL is evident based on results for a similar sample of children.

Future directions

Suggestions for future research include the need to further validate the word list utilised here as a single-word standardised speech assessment test for CWHL. Speech assessment for CWHL should include a balanced representation of speech sounds in onset and coda position which vary in syllable structure (monosyllabic, disyllabic and multisyllabic). Further research is also needed to investigate the speech profile of CWHL based on a connected speech sample in order to have a more holistic representation of children's speech problems in everyday life. Even though CWHL produced more vowels in their phonetic inventory than consonants and had better PVC correct, some children still use monophthongized processes. Therefore, further study is needed to examine monothong and diphthong development in CWHL with different degrees of HL.

The current study found speech delay in CWHL and forms the basis for future prospective longitudinal studies of CWHL to determine optimal speech therapy approaches for young CWHL. A longitudinal study is needed to examine the effect of other important factors such as amount of hearing aid and CI use (Walker et al., 2013), the effectiveness of the hearing aid fitting in providing access to the speech cues (McCreery et al., 2013), parental input (Ambrose et al., 2014), and the type and extent of therapy on speech profile of CWHL.

APPENDIX

Family/teacher questionnaire for children with hearing loss

Section A: <u>Child's information</u>:

Child's name: ________________________(first name) ____________________(family name)

Child's date of birth: ________/________/__________ (day/month/year)

School: _______________________________________

Sex: ☐ M ☐ F

Section B: Please answer for the following questions. Tick only one box for each question.

1. Does the child have difficulty telling you what he or she wants? ☐never ☐occasionally ☐about half the time ☐frequently ☐ always
2. Does the child have difficulty communicating with teachers? ☐never ☐occasionally ☐about half the time ☐frequently ☐ always
3. Do you ask the child to repeat what she/he said because his or her speech is not clear to you? ☐never ☐occasionally ☐about half the time ☐frequently ☐ always
4. Do you feel the child's speech problem affects the child's interactions with other children? ☐ never ☐occasionally ☐about half the time ☐frequently ☐ always
5. Are you satisfied with the child's current speech performance? ☐ always ☐frequently ☐about half the time ☐ occasionally ☐ almost never
6. Have you noticed an improvement in the child's speech within the last 6 months? ☐ significant improvement ☐ noticeable improvement ☐ a little improvement ☐ no improvement
7. How much do you understand of the child's speech? 1 = I almost always understand the child's speech 2 = I almost always understand. However, I need to listen carefully. 3 = I typically understand 50% of the child's speech 4 = I typically understand 25% of the child's speech 5 = The child's speech is very hard to understand. I typically understand only occasional, isolated words and/or phrases 6 = I never understand the child's speech

Please add any additional information you would like it to share with us regarding the child's speech or language or communication abilities with other children

DEPARTMENT OF PSYCHOLOGY (Speech Science)
Speech Language Therapy

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Innes Auckland, New
Zealand
The University of
Auckland
Private Bag 92019
Auckland, New Zealand

(Date)

Participant Information Sheet – Manager/ Principal

Title: Speech production of children with hearing loss in New Zealand

To the Manager/Principal of (name of school),

My name is Areej Asad, and I am a postgraduate student in Speech Language Therapy programme at The University of Auckland. As part of my study I am conducting a research project, studying the speech production of children with hearing loss in New Zealand by testing the speech of children with hearing impairment and their hearing peers. The speech of typically developing children contains developmental phonological patterns such as pronouncing “shoe” as [tu]. Most of the developmental phonological patterns disappear from the speech of typical children by the age of five. These speech patterns may remain in the speech of children of hearing loss. The purpose of this study is to explore whether children with hearing impairment in New Zealand demonstrate the same phonological patterns as children with typical development and children with hearing loss in overseas studies. We will recruit two groups of participants with 15 to 20 children in each group, aged between 5 to 7 years. The first group will be children with moderate to profound hearing loss and the second group will be children with typical development and normal hearing (control group). Children will speak English as their main language, but children can be in the study if other languages are spoken at home.

I would like to invite your school to participate in this research, and would appreciate any assistance you could offer. I am looking for 15 to 20 children aged 5-7 to participate. If you are willing for your school to be involved, I will spend 30 – 45 minutes per session with each child, for a total of 3-5 sessions across a two week period. If you are happy to support this research I would require you or your staff to invite children with moderate to profound hearing loss aged 5 or 6 years who speak English as their main language to participate. We would like to match each child with hearing loss with a child who is the same age and gender who has normal hearing so we would also be grateful if these children could be invited to participate. I seek your assurance that the participation/non-participation of children in this study will not affect their learning support (for schools), nor the relationship between your school/agency and the family. You are free to withdraw your school from the research at any time without giving a reason up to one month after beginning participation in the study. Upon completion of the study, I will be able to provide you with a copy of the overall results at your request.

Each child involved in this research will receive a speech assessment. Children will receive $25 gift vouchers for their participation. Families who are travelling for appointments will be offered $20 petrol vouchers. If any speech problems are identified for children with normal hearing, children will be offered an appointment at The University of Auckland's Speech Language Therapy clinic (a free service), or will be referred to another speech language therapist for therapy. If speech problems are identified for children with hearing loss, a report will be sent to their current service provider (for example, Kelston Deaf Education Centre and the Ministry of Education Special Education).

Testing would be done at school/ in a speech clinic in a location convenient for the children, to reduce interference to the school day. The speech evaluation requires the child to look at pictures or objects and name them. The researcher will then tell a story and the child will retell it. If at any time in the session a child becomes tired, distressed, or uncooperative, testing will stop and be resumed later or in another session if the child is happy to continue. I will record what each child says and how the word is pronounced. Children with hearing loss who have speech errors will be retested after six months. Test and retest scores will be compared, to observe if there is any progress in their speech production.

I will be looking for common phonological patterns and unresolved speech problems in the speech of children with hearing loss by comparing their speech to their hearing peers of the same age. Sessions will be video-taped and audio-taped. All participants will be assigned a number and individual results will be assigned a code number that will be used when reporting any results of the research. The results will be published in a peer-reviewed journal. At no time would any reference be made that would specifically identify research participants to anyone other than the researchers involved with the study.

Results (including video-recording and audio-recording) will be held in a location separate to the research consent forms. Results and consent forms will be kept in a locked cabinet on the University premises accessible only to the researchers participating in the study. Assessment results will be kept for 6 years after research participation is completed. After the stipulated period the consent forms will be destroyed by shredding. Video and record materials will destroyed by wiping or destruction of the disks.

This research will provide speech language therapists with a better understanding of what types of speech errors children with hearing loss may have compared to their age peers and will help us to identify which speech therapy approach is best for children with hearing loss.

I have attached a copy of the parent information letter and consent form for your information. If your school is able to participate, I will provide you with copies of the letters and consent forms, for distribution. Parents who agree for their child to participate will be asked to return signed consent forms to Areej by an agreed date. I will then contact you to arrange a suitable testing time and dates for your school.

Please be assured that your school's participation is completely voluntary, and that your decision either way will have no impact on the University of Auckland's relationship with your school.

I will contact you by telephone with in the next two weeks to discuss this further. If you have any questions in the meantime, please feel free to contact me or either of my supervisors using the email addresses or telephone numbers at the end of this letter.

Thank you for your time, and I look forward to speaking with you soon.

Yours sincerely

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For ethical concerns contact: The Chair, The University of Auckland Human Participants Ethics Committee, Office of the Vice Chancellor, Room 005 Alfred Nathan House 24 Princes Street, Auckland. Telephone: 3737599 ext. 87830.

APPROVED BY THE UNIVERSITY OF AUCKLAND HUMAN PARTICIPANTS ETHICS COMMITTEE ON 13-Feb-2012 TO 22-Dec-2014 FOR 3 YEARS. REFERENCE NUMBER 7730

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Auckland, New Zealand

(Date)

Participant Information Sheet – Teacher/ Advisor on deaf children/ Speech language therapist

Title: Speech production of children with hearing loss in New Zealand

My name is Areej Asad, and I am a postgraduate student in Speech Language Therapy programme at The University of Auckland. As part of my study I am conducting a research project, studying the speech production of children with hearing loss in New Zealand by testing the speech of children with hearing impairment and their hearing peers. The purpose of this study is to explore whether children with hearing impairment in New Zealand demonstrate the same speech difficulties as children with typical development and children with hearing loss in overseas studies. We will recruit two groups of participants with 15 to 20 children in each group, aged between 5 to 7 years. The first group will be children with moderate to profound hearing loss and the second group will be children with typical development and normal hearing (control group). Children will speak English as their main language, but children can be in the study if other languages are spoken at home.

I would like to invite you to participate in this research, and would appreciate your assistance with recruitment of children for the study. I will spend 30 – 45 minutes per session with each child, for a total of 3-5 sessions across a two week period. If at any time in the session a child becomes tired, distressed, or uncooperative, testing will stop and be resumed later or in another session if the child is happy to continue. Children can choose to discontinue participation at any stage.

If you are happy to support this research, I will ask you take the following part in the research:

1. Invite parents of children aged 5 or 6 years with moderate to profound hearing loss who speak English as their main language to participate.
2. Invite parents of children with normal hearing to participate; these children will be the same age and gender as children in the study with a hearing loss.
3. Provide families with the information sheet, the consent form to sign and the questionnaire. Parents will complete the enclosed consent form and questionnaire and return them to Areej in the enclosed envelope. The date and time for testing will be coordinated by the Areej directly with the school to minimize disruption. If the parents have any questions regarding the research, they can contact me or my supervisors.

You are free to withdraw from the research at any time without giving a reason up to a month after beginning participation in the study. It is essential that parents and the children feel free to choose whether to participate or decline, so I seek for your assurance that the participation/non-participation of children in this study will not affect their learning support (for schools), nor the relationship between your school/agency and the family.

Each child involved in this research will receive a speech assessment. Children will receive $25 gift vouchers for their participation. Families who are travelling for appointments will be offered $20 petrol vouchers. . If any speech problems are identified for children with normal hearing, children will be offered an appointment at The University of Auckland’s Speech Language Therapy clinic (a free service), or will be referred to another speech language therapist for therapy. If speech problems are identified for children with hearing loss, a report will be sent to their current service provider (for example, Kelston Deaf Education Centre and the Ministry of Education Special Education).

The speech assessment will be done at school/in a speech clinic in a location convenient for the children, so that there is minimal interference with the school day. The speech evaluation requires the child to look at pictures or objects and name them. The researcher will then tell a story and the child will retell it. The child's words will be audio and video recorded. Children with hearing loss who have speech errors will be retested after six months. Test and retest scores will be compared, to observe if there is any progress in their speech production.

I will be looking for common speech error patterns and unresolved speech problems in the speech of children with hearing loss by comparing their speech to their hearing peers of the same age. All participants will be assigned a number and individual results will be assigned a code number that will be used when reporting any results of the research. The results will be published in a peer-reviewed journal. At no time would any reference be made that would specifically identify research participants to anyone other than the researchers involved with the study. Upon completion of the study, I will be able to provide you with a summary of the overall results at your request.

Results (including video-recording and audio-recording) will be held in a location separate to the research consent forms. Results and consent forms will be kept in a locked cabinet on the University premises accessible only to the researchers participating in the study. Assessment results will be kept for 6 years after research participation is completed. After the stipulated period the consent forms will be destroyed by shredding. Video and record materials will destroyed by wiping or destruction of the disks.

This research will provide speech language therapists with a better understanding of what types of speech errors children with hearing loss may have compared to their age peers and will help us to identify which speech therapy approach is best for children with hearing loss.

I have attached a copy of the parent information letter and consent form for your information. If you are able to participate, I will provide you with copies of the participant's information sheet and consent forms, for distribution to students. Parents who agree for their child to participate will be asked to return the consent form and questionnaire to Areej in the enclosed envelope by an agreed date. I will then contact you to arrange a suitable testing time and dates for your school.

Please be assured that your participation is completely voluntary, and that your decision either way will have no impact on the University of Auckland's relationship with your school.

If you agree to participate please complete the consent form and return it to me. When I receive your consent form I will provide you with the information sheet, consent forms and the questionnaire for parents. If you have any questions in the meantime, please feel free to contact me or either of my supervisors using the email addresses or telephone numbers at the end of this letter.

Thank you for your time, and I look forward to speaking with you soon.

Yours sincerely

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Ms Liz Fairgray
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DEPARTMENT OF PSYCHOLOGY (Speech Science)
Speech Language Therapy

THE UNIVERSITY OF AUCKLAND
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The University of Auckland
Private Bag 92019
Auckland, New Zealand

(Date)

Participant Information Sheet – Parents / Caregivers

Title: Speech production of children with hearing loss in New Zealand

Dear Parents/ Caregivers,

I am writing to invite your child to participate in a study of the speech production of children with hearing loss in New Zealand. My name is Areej Asad, and I am a PhD student in the Speech Language Therapy programme at The University of Auckland. As part of my study I am conducting a research project, studying the speech production of children with hearing loss in New Zealand by testing the speech of children with hearing impairment and their hearing peers. The speech of typically developing young children contains developmental patterns such as pronouncing "shoe" as [tu]. Most of these patterns disappear from the speech of typical children by the age of five but these speech patterns may remain in the speech of children with hearing loss. Hence, some children with hearing loss may need speech therapy.

I would like to test two groups of participants with 15 to 20 children in each group, aged between 5 and 7 years. The first group will be children with moderate to profound hearing loss and the second group will be children with no hearing difficulties. If children from bilingual families are keen to participate, they may be included as long as English is one of the languages spoken at home. If your child has a hearing loss, we will ask your permission to obtain a copy of a recent hearing tests and hearing aid or cochlear implant results from your audiologist. This will assist in the interpretation of results, by indicating which speech sounds are audible.

Each child involved in this research will receive a speech assessment. Children will receive $25 gift vouchers for their participation. Families who are travelling for appointments will be offered $20 petrol vouchers. . If any speech problems are identified for children with normal hearing, children will be offered an appointment at The University of Auckland's Speech Language Therapy clinic (a free service), or will be referred to another speech language therapist for therapy. If speech problems are identified for children with hearing loss, a report will be sent to their current service provider (for example, Kelston Deaf Education Centre and the Ministry of Education Special Education).

The test time needed with each child will be 30 – 45 minutes per session, for a total of 3-5 sessions across a two week period. Testing will be done at school/in a speech clinic in a location convenient for the children, so that there is minimal interference with the school day. The speech evaluation requires the child to look at pictures or objects and name them. The researcher will then tell a story and the child will retell it. If at any time in the session a child becomes tired, distressed, or uncooperative, testing will stop and be resumed later or in another session.

I will record what each child says and how the word is pronounced. Children with hearing loss who have speech errors will be retested after six months. Test and retest scores will be compared, to observe if there is any progress in their speech production. I will be looking for common speech patterns and any unresolved speech difficulties by comparing the children's speech to other children the same age without hearing difficulties.

All children involved will be video-taped and audio-taped saying the words so that their speech can be analysed afterwards. If your child participates in the study, all personal information will remain strictly confidential. Individual results will be assigned a code number that will be used when reporting any results of the research. The results will be published in a peer-reviewed journal. At no time will there be any reference that would specifically identify research participants to anyone other than the researchers involved with the study.

Only myself, a university speech language therapist who signs a confidentiality agreement, and supervisors at the University of Auckland may hear the recordings made on the tape and see the written data of each child. Results (including video-recording and audio-recording) will be held in a location separate to the research consent forms. Results and consent forms will be kept in a locked cabinet on the University premises accessible only to the researchers participating in the study. Assessment results will be kept for 6 years after research participation is completed. After the stipulated period the consent forms will be destroyed by shredding. Video and record materials will destroyed by wiping or destruction of the disks.

At the end of the study you may have a summary of your child's test results and a summary of the research findings upon your request.

Your Principal/ Advisor on deaf children/ Speech language therapist/Teacher has given their assurance that the participation/non-participation of children in this study will not affect their learning support (for schools), nor the relationship between the school/agency and your family. You are free to withdraw your child from the research without giving a reason up to one month after participation in the study. Your participation in the study is voluntary, and the decision regarding participation has no impact on the University's relationship with the school or with you and your family.

If you agree for your child to participate, please complete the enclosed consent form, questionnaire. Then return it to the researchers in the enclosed envelope by an agreed date. The date and time for testing will be coordinated by the Areej directly with the school. If you have any questions in the meantime, please feel free to contact me or either of my supervisors using the email addresses or telephone numbers at the end of this letter.

Thank you for your time.

Yours sincerely

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Contact details of researchers
The Head of the Department of Psychology is:
Associate Professor Douglas Elliffe
Department of Psychology

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Child Information Sheet

(To be read to the child)

Title: Speech production of children with hearing loss in New Zealand

My name is Areej Asad. I am a postgraduate student at the University of Auckland and I am learning about how children with hearing loss in New Zealand speak.

Would you like to help me? ___Yes / No____

I would see you for a total of 3 to 5 times over a time span of two weeks. The time we would spend together would be about 30 to 45 minutes. When I see you I will show you some pictures and then ask you to name these pictures. After that you will need to look at some other pictures. I will tell you a story about these pictures and then you will tell the same story back to me. I will video tape and audio record you talking on a tape recorder so that I can listen to you later. After I listen to your tape I will also let another speech and language therapist friend listen to your tape.

If you want me to stop me taping you can tell me at any time and we will turn the recorder off. I will make a report where I write down the way you say different words. I will make sure that no-one but you, me and my teacher/supervisor see and listen to the tape. I will also keep the tape in a safe place locked away for six years. After we finish looking at the pictures, I will let your parents/guardians know how you did. I’m looking forward to working with you and I am happy you can help me. You do not have to do this if you don’t want to, and we can stop if you get tired or do not want to do this anymore. OK? Do you have any questions?

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Consent Form – Manager/ Principal

Title: Speech production of children with hearing loss in New Zealand

- I have read the information sheet for teacher/advisor on deaf children/ speech language therapist in the study on speech production of children with hearing loss in New Zealand. I understand both the nature of the research and the reasons why my school or clinic was contacted to be involved.

- I have had an opportunity to discuss this study and ask questions. I am satisfied with the answers I have been given.

- I agree for children at my school to participate in this study which aims to explore whether children with hearing impairment in New Zealand demonstrate the same phonological patterns as children with typical development and children with hearing loss in overseas studies aged 5;0 -7;0 (years;months).

- I give assurance that the participation/non-participation of children in this study will not affect their learning support (for schools), nor the relationship between your school/agency and the family.

- I understand that taking part in this study is voluntary and that I may withdraw my school's/clinic's participation at any time up to one month after beginning and this will in no way affect my relationship with the University of Auckland.

- I understand that each child will participate in 3 -5 sessions of about 30 - 45 minutes across a two week period at school/in clinic.

- I understand that children with hearing loss will be invited to be retested after six months.

- I agree to audio and video recording of children at school/in clinic, and I consent to the use of recording for test analysis purposes. I understand that it will be heard by Areej Asad, a university student who is an experienced speech language therapist, and her supervisors.

- I understand that speech testing sessions will take place at school/in clinic, and that these sessions will be video and audio recorded. I understand that all information gathered about each child during sessions will be kept confidential.

- I understand that consent forms and data collected during this study will be stored separately in a locked filing cabinet at the University of Auckland.
- I understand that consent forms, video and record materials will destroyed after a period of six years.
- I understand that assessment results will be kept for a period of six years.

I would like to receive a copy of the overall findings of my school. *YES / NO*

Manager / Principal Name:

____

Phone Numbers: ___________________________ Email address:

____

Signature: ____

Date: _______/______/________

THIS CONSENT FORM WILL BE HELD FOR A PERIOD OF SIX YEARS

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Consent Form – Teacher/ Advisor on deaf children/ Speech language therapist

Title: Speech production of children with hearing loss in New Zealand

- I have read the information sheet for teacher/advisor on deaf children/ speech language therapist in the study on speech production of children with hearing loss in New Zealand. I understand both the nature of the research and the reasons why my school or clinic was contacted to be involved.

- I have had an opportunity to discuss this study and ask questions. I am satisfied with the answers I have been given.

- I understand that taking part in this study is voluntary and that I may withdraw my participation at any time up to one month after beginning and this will in no way affect my relationship with the University of Auckland.

- I give assurance that the participation/non-participation of children in this study will not affect their learning support (for schools), nor the relationship between your school/agency and the family.

- I understand that each child will participate in 3 -5 sessions of about 30 - 45 minutes across a two week period at school/in clinic.

- I understand that children with hearing loss will be invited to be retested after six months.

- I understand that speech testing sessions will take place at school/in clinic, and that these sessions will be video and audio recorded.

- I understand that all information gathered about each child during sessions will be kept confidential.
- I understand that consent forms and data collected during this study will be stored separately in a locked filing cabinet at the University of Auckland.

• I understand that consent forms, video and record materials will destroyed after a period of six years.

• I understand that assessment results will be kept for a period of six years.

I would like to receive a copy of the overall findings of my school/patients. *YES / NO*

Teacher/Advisor on deaf children/ Speech language therapist Name: ______________________________

Phone Numbers: _____________________________ Email address: _________________________

Signature: ____

Date: _______/______/________

THIS CONSENT FORM WILL BE HELD FOR A PERIOD OF SIX YEARS

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Auckland, New Zealand

Consent Form – Parents/ Caregivers

Title: Speech production of children with hearing loss in New Zealand

- I have read and I understand the information sheet for participants taking part in the study on speech production of children with hearing loss in New Zealand.

- I have had the opportunity to discuss this study. I am satisfied with the answers I have been given.

- I understand that taking part in this study is voluntary and that I may withdraw my participation at any time up to one month after beginning participation.

- I understand that Principal/ Advisor on the deaf/ Speech language therapist/Teacher has given their assurance that the participation/non-participation of your child in this study will not affect his/her learning support (for schools), nor the relationship between the school/agency and your family.

- I understand that each child will participate in 3 -5 sessions of about 30 - 45 minutes across a two week period at school/in speech clinic.

- I understand that speech testing sessions will take place at school/in clinic, and that these sessions will be video and audio recorded.

- I understand that children with hearing loss will be invited to be retested after six months.

- I agree to audio and video recording of my child's speech at school, and I consent to the use of recording for test analysis purposes. I understand that it will be heard by Areej Asad, a university speech language therapist, and supervisors.

- I understand that my choice to allow my child to participate or not to participate will not affect your eligibility to attend the University of Auckland's Listening and Language Clinic, or any other University of Auckland clinic.
- I understand that my participation in this study is confidential and that no material that could identify me and/or my child will be used in any reports on this study.

- I understand that, with my permission, the researchers will obtain a copy of recent hearing test and hearing aid/cochlear implant results from my audiologist.

- I understand that consent forms and data collected during this study will be stored separately in a locked filing cabinet at the University of Auckland.

- I understand that assessment results will be kept for a period of six years.

- I understand that consent forms, video and record materials will destroyed after a period of six years.

- I understand if any difficulties in my child's speech are identified during the study, the researcher is obliged to inform me.

- I have had time to consider whether to take part.

- I know whom to contact if I have any questions about the study.

I would like a copy of my child's results: Yes / No
I would like to have a summary of the of the research findings Yes / No

Postal address for results:
____
____

I ___________________________________ (full name) hereby consent to taking part in this

research study.

Signature: ____

Contact Phone Numbers: _____________________________________ Date:
___/___/____

Email address: ____

I am the child's: Mother / Father / Guardian

THIS CONSENT FORM WILL BE HELD FOR A PERIOD OF SIX YEARS

APPROVED BY THE UNIVERSITY OF AUCKLAND HUMAN PARTICIPANTS ETHICS COMMITTEE ON 13-Feb-2012 TO 22-Dec-2014 FOR 3 YEARS. REFERENCE NUMBER 7730

DEPARTMENT OF PSYCHOLOGY (Speech Science)
Speech Language Therapy

THE UNIVERSITY OF AUCKLAND
NEW ZEALAND

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The University of Auckland
Private Bag 92019
Auckland, New Zealand

Child Assent Form

(To be read aloud to the child)

THIS ASSENT FORM WILL BE HELD FOR A PERIOD OF SIX YEARS

Title: Speech production of children with hearing loss in New Zealand

I want to make sure you are happy to do this little project with me. I will ask you some questions. If you think the things I read to you are true, say "Yes". If you do not think they are right, say "No". I will record the questions and your answers on my tape recorder, so my teachers/supervisors know that I have explained everything to you.

- I have had the information sheet read to me.
- I understand that I will tell you what these pictures are
- I understand that Areej will tell me a story and I will tell the same story back to her.
- I understand that Areej will video tape and audio record what I say.
- I understand that Areej can listen to me talking later.
- I understand that I can stop if I want to, and that everyone will be Ok with that.
- I understand that Areej might write some of my answers in a report, but that no one else (except Areej's supervisors/teachers) will know that the answers are mine, because my name will be not written in it.
- I understand that what I say and the tape will be kept for six years in a safe place.
- Areej has answered all the questions that I have.
- I understand that Areej can tell my parents how I did.

If you are happy to do this with me, please read this sentence after me:

‘My name is ______________. I understand what Areej will ask me to do and I am happy to do it. Today is _______________’.

APPROVED BY THE UNIVERSITY OF AUCKLAND HUMAN PARTICIPANTS ETHICS COMMITTEE ON 13-Feb-2012 TO 22-Dec-2014 FOR 3 YEARS. REFERENCE NUMBER 7730

Ethics Approval

Office of the Vice-Chancellor
Research Integrity Unit

THE UNIVERSITY OF AUCKLAND
NEW ZEALAND
Te Whare Wānanga o Tāmaki Makaurau

The University of Auckland
Private Bag 92019
Auckland, New Zealand

Level 10, 49 Symonds Street
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Extension: 87830 / 83761
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UNIVERSITY OF AUCKLAND HUMAN PARTICIPANTS ETHICS COMMITTEE

22-Dec-2011

MEMORANDUM TO:

Assoc Prof Suzanne Purdy
Psychology

Re: Application for Ethics Approval (Our Ref. 7730)

The Committee considered your application for ethics approval for your project titled **Speech production of children with hearing loss in New Zealand** on 21-Dec-2011.

Ethics approval was given for a period of three years with the following comment(s).

1) The revisions made directly to the Committees concerns outlined in the previous memorandum have been approved.

2) It is preferred that the proposed addition of an articulation subtest be submitted as a Request for Change, and therefore it has not been included as part of this approval.

3) The minor amendments requested that related to data analysis by KLPA-2 and Praat software are approved.

The expiry date for this approval is 22-Dec-2014.

If the project changes significantly you are required to resubmit a new application to the Committee for further consideration.

In order that an up-to-date record can be maintained, you are requested to notify the Committee once your project is completed.

The Chair and the members of the Committee would be happy to discuss general matters relating to ethics approvals if you wish to do so. Contact should be made through the UAHPEC secretary at humanethics@auckland.ac.nz in the first instance.

All communication with the UAHPEC regarding this application should include this reference number: **7730**.

(This is a computer generated letter. No signature required.)

Secretary
University of Auckland Human Participants Ethics Committee

c.c. Head of Department / School, Psychology
Miss Areej Asad
Dr Douglas Elliffe

Additional information:

1. Should you need to make any changes to the project, write to the Committee giving full details including revised documentation.

2. Should you require an extension, write to the Committee before the expiry date giving full details along with revised documentation. An extension can be granted for up to three years, after which time you must make a new application.

3. At the end of three years, or if the project is completed before the expiry, you are requested to advise the Committee of its completion.

4. Do not forget to fill in the 'approval wording' on the Participant Information Sheets and Consent Forms, giving the dates of approval and the reference number, before you send them out to your participants.

5. Send a copy of this approval letter to the Manager - Funding Processes, Research Office if you have obtained funding other than from UniServices. For UniServices contract, send a copy of the approval letter to: Contract Manager, UniServices.

6. Please note that the Committee may from time to time conduct audits of approved projects to ensure that the research has been carried out according to the approval that was given.

Ethics Revision

Office of the Vice-Chancellor
Research Integrity Unit

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UNIVERSITY OF AUCKLAND HUMAN PARTICIPANTS ETHICS COMMITTEE

22-Dec-2011

MEMORANDUM TO:

Assoc Prof Suzanne Purdy
Psychology

Re: Application for Ethics Approval (Our Ref. 7730)

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Ethics approval was given for a period of three years with the following comment(s).

1) The revisions made directly to the Committees concerns outlined in the previous memorandum have been approved.

2) It is preferred that the proposed addition of an articulation subtest be submitted as a Request for Change, and therefore it has not been included as part of this approval.

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