SPEECH RECOGNITION IN CHILDREN WITH UNILATERAL AND BILATERAL COCHLEAR IMPLANTS IN QUIET AND IN NOISE

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DECLARATION

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the owner of the copyright thereof (unless to the extent explicitly otherwise stated) and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

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GLOSSARY OF TERMS

A glossary of key terms is included which provides a brief description of some of the terms and abbreviations used in the research project.

ACE: Advance combination encoder. A coding strategy, which allows for the spectral pattern of the spectral maxima speech processing strategy to be presented at high temporal rates (Clark, 2003, p. 425).

BiCI (Bilateral cochlear implants): Having separate cochlear implants implanted in both the left and right ears.

Bilateral: On both sides; involving both ears (Tye-Murray, 1998, p. 503).

Binaural hearing: Hearing with both ears (Cole & Flexer, 2007, p. 323). The ability to compare and benefit from the acoustic information arriving at the two ears (Akeroyd, 2006, p. S25).

CI 1: First cochlear implant received.

CI 2: Second cochlear implant received.

Closed-set: A clearly defined or “limited” set of responses. All possible responses are specified (McConkey Robbins, 2000b, p. 332).

Competing speech/Background noise: Any unwanted sound that may or may not interfere with listening (Cole & Flexer, 2007, p. 323).

Monaural: Listening with one ear (Martin & Clark, 2006, p. 448).

Open-set: On hearing the test item, no response alternatives are provided and the listener typically repeats what is heard (Kirk, 2000, p. 228).

Signal to noise ratio (SNR): The relationship between a primary signal such as the teacher's or parent's speech and background noise (Cole & Flexer, 2007, p. 334).

Speech perception: The ability to receive a spoken message through hearing (McKirdy & Klimovitch, 1994, p. 762).

Speech recognition: The ability to perceive and identify speech units (Tye-Murray, 1998).

Speech recognition threshold (SRT): The threshold of intelligibility of speech; the lowest intensity at which at least 50 percent of a list of spondees can be identified correctly (Martin & Clark, 2006, p. 453).

Spondee: A two syllable word pronounced with equal stress on both syllables (Martin & Clark, 2006, p. 453).

Unilateral: Pertaining to one ear only (Stach, 1998, p. 91).

ABSTRACT

Individuals are increasingly undergoing bilateral cochlear implantation in an attempt to benefit from binaural hearing. The main aim of the present study was to compare the speech recognition of children fitted with bilateral cochlear implants, under binaural and monaural listening conditions, in quiet and in noise. Ten children, ranging in age from 5 years 7 months to 15 years 4 months, were tested using the Children's Realistic Index for Speech Perception (CRISP). All the children were implanted with Nucleus multi-channel cochlear implant systems in sequential operations and used the ACE coding strategy bilaterally. The duration of cochlear implant use ranged from 4 years to 8 years 11 months for the first implant and 7 months to 3 years 5 months for the second implant. Each child was tested in eight listening conditions, which included testing in the presence and absence of competing speech. Performance with bilateral cochlear implants was not statistically better than performance with the first cochlear implant, for both quiet and noisy listening conditions. A ceiling effect may have resulted in the lack of a significant finding as the scores obtained during unilateral conditions were already close to maximum. A positive correlation between the length of use of the second cochlear implant and speech recognition performance was established. The results of the present study strongly indicated the need for testing paradigms to be devised which are more sensitive and representative of the complex auditory environments in which cochlear implant users communicate.

Keywords: cochlear implants, unilateral, bilateral, speech perception, speech recognition, binaural benefit, quiet, competing noise

ABSTRAK

Individue ondergaan toenemend bilaterale kogleêre inplantings in ‘n poging om die voordeel van binourale gehoor te geniet. Die doel van die huidige studie was om spraakherkenning van kinders met bilaterale kogleêre inplantings, onder binourale en monourale luistersituasies, in stilte en geraas te vergelyk. Tien kinders, tussen die ouderdomme van 5 jaar 7 maande en 15 jaar 4 maande, is met die *Children's Realistic Index for Speech Perception* (CRISP) getoets. Al die kinders is met Nucleus multi-kanaal kogleêre inplantingsisteme in opeenvolgende operasies ingeplant en het die ACE koderingsstrategie bilateraal gebruik. Duur van die gebruik van die kogleêre inplantings het van 4 jaar tot 8 jaar 11 maande vir die eerste inplanting en 7 maande tot 3 jaar 5 maande vir die tweede inplanting gewissel. Elke kind is in agt luistersituaties getoets, wat toetsing in die teenwoordigheid en afwesigheid van mededingende spraak ingesluit het. Prestasie in beide stil en raserige luistersituasies was nie statisties beter met bilaterale kogleêre inplantings teenoor prestasie met die eerste inplanting nie. ’n Plafon-effek mag hierdie gebrek aan ’n beduidende bevinding veroorsaak het, aangesien die tellings wat tydens die unilaterale situasies verkry is, alreeds byna maksimaal was. ‘n Positiewe korrelasie is tussen die tydsduur van kogleêre inplantingsgebruik, spesifiek die tweede inplanting, en prestasie in spraakherkenning bevestig. ‘n Sterk aanbeveling wat vanuit die huidige studie spruit, is die behoefte aan die ontwikkeling van toetsmodelle wat meer sensitief en verteenwoordigend is van die komplekse luisteromgewings waarbinne inplantingsgebruikers kommunikeer.

Sleutelwoorde: kogleêre inplantings, unilateraal, bilateraal, spraakpersepsie, spraakherkenning, binourale voordeel, stilte, mededingende geraas

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CHAPTER 1: INTRODUCTION

1.1 INTRODUCTION

A cochlear implant is a sensory device that provides hearing to facilitate verbal communication, rather than a cure for sensorineural hearing loss (Niparko, 2000). Today, approximately 30 years after its initial development, the cochlear implant is considered to be the treatment of choice for severe to profound hearing loss.

Cochlear implants are associated with improved speech perception abilities (Dorman, 2000), improved speech production (Svirsky & Chin, 2000) and are also beneficial for language development in children (McConkey Robbins, 2000a). According to the literature, multi-channel cochlear implants have enabled congenitally deaf children to develop speech and language skills that are superior to those of their hearing impaired peers who have not undergone cochlear implantation (Tomblin, Spencer, Flock, Tyler & Gantz, 1999; Tomblin, Spencer & Gantz, 2000). Despite the significant benefits obtained, most cochlear implant users, who traditionally have been implanted with one cochlear implant, still have poor localising skills and have difficulty understanding speech in noisy environments (Long, Carlyon, Litovsky & Downs, 2006). In normal hearing listeners, binaural hearing minimizes these difficulties. In an attempt to capture the benefits of binaural hearing, the trend towards providing bilateral cochlear implants has been increasing. The basis for this intervention strategy is the hypothesis that since persons with normal hearing rely on two ears for speech perception in noise and for localization, persons with hearing impairments should also be provided with the opportunity of using both ears (Litovsky, Johnstone & Godar, 2006). The access to binaural acoustic information should ultimately result in enhanced listening experiences in complex everyday auditory environments and improved quality of life. In addition, the effects of auditory deprivation may be negated by the provision of bilateral cochlear implants (Bauer, Sharma, Martin & Dorman, 2006).

Until approximately 1995, only a few individuals received bilateral cochlear implants, usually for reasons other than to restore binaural hearing. These individuals included:

persons who received a second implant because they performed poorly with their first implant; or persons who received a second implant as part of a technological upgrade even though their first implant was still functioning adequately (Gantz et al., 2002; Müller, Schön & Helms, 2002). This, however, has changed in recent years as individuals are undergoing bilateral cochlear implantation in an attempt to benefit from the binaural advantage, rather than for the above reasons.

Recent studies (Buss et al., 2008; Dunn, Tyler, Oakley, Gantz & Noble, 2008; Galvin, Mok & Dowell, 2007; Gordon, Valero & Papsin, 2007; Litovsky et al., 2006; Ricketts, Grantham, Ashmead, Haynes & Labadie, 2006; Scherf et al., 2007; Tyler, Dunn, Witt & Noble, 2007; Tyler, Noble, Dunn & Witt, 2006) have focused on the advantages of bilateral cochlear implants. Following on the reports that bilateral implantation improves speech perception in noise, this study was undertaken to investigate the speech recognition abilities of children, with unilateral and bilateral cochlear implants, in quiet and in noise.

1.2 STRUCTURE OF THESIS

This thesis is divided into the following chapters:

- Chapter 1 – Introduction: In this chapter, the reader is given an orientation to the topic of the research, as well as the nature and scope of the study.

- Chapter 2 – Literature Review: In this chapter, previous literature is reviewed. In addition, a background of the field of study is provided.

- Chapter 3 – Methodology: In this chapter, the aims of the study are stated, as well as, the procedures and protocols that were followed during the research project.

- Chapter 4 – Results and Discussion: In this chapter, the findings are reflected upon and discussed.

- Chapter 5 – General Discussion and Conclusions: This chapter presents an overview and discussion of the relevant findings, relating to the aims of the study.

- Chapter 6 – Critique and Implications: This chapter provides a critique of certain aspects of the study and suggests a number of implications of these findings.

- References: This section lists all material cited in this report.

- Appendices: This section contains supplementary information and data.

CHAPTER 2: LITERATURE REVIEW

2.1 COCHLEAR IMPLANTS

A cochlear implant, as defined by Clark (2003), is a sensory device that is used to establish functional hearing in people with severe to profound hearing loss. The basic components of any cochlear implant system are: an electrode array, receiver-stimulator, microphone, transmitter and processor. Of these components, the first two are placed internally (i.e. implanted), whereas the rest are worn behind the external ear (Waltzman, 2000). The function of a cochlear implant is not to restore normal hearing per se, but rather to provide the individual with hearing sensitivity within the frequency range considered to be important for speech (O' Donoghue, Nikolopoulos & Archbold, 2000). This is achieved by stimulating the auditory nerve and circumventing the damaged or undeveloped inner ear (Clark, 2003). The acoustic vibrations entering the microphone are converted into electrical stimuli by the speech processor (Wilson, 2000). These electrical impulses are then transmitted via the auditory nerve to the auditory centres of the brain, where it is perceived as sound (Rubinstein, 2004).

One of the main aims for providing a child with a cochlear implant is to improve the auditory ability to such a level that enables the child to develop and understand spoken language. According to research (Fink et al., 2007; O'Donoghue et al., 2000), the ability of that child to learn spoken language is considered to be an indicator of benefit and/or success. With the advances in cochlear implant technology, the single-channel devices which were initially implanted were replaced with multi-channel implants. This has enabled improved speech processing, resulting in speech understanding for open-set speech tasks (Clark, 2003). Multi-channel cochlear implants have improved speech perception in adults and children with post-lingual deafness and have also allowed congenitally deaf children to develop expressive and receptive language skills, which are significantly better than those of their hearing impaired peers, who had not received cochlear implants (Tomblin et al., 1999; Tomblin et al., 2000).

According to Wilson (2000), unilateral cochlear implant users, even those who perform well with their implants still do not match the performance of normal hearing individuals, especially in noisy or complex listening environments. Research by Dorman, Loizou, Fitzke and Tu (1998; in Clark, 2003) suggest that twelve to twenty channels are required for optimum speech recognition in noise, depending on the signal-to-noise ratio (SNR), and only five channels are required in quiet. Additional research indicates that even if the number of channels used were to be increased significantly, unilateral cochlear implant users would still have difficulty in perceiving speech in the presence of fluctuating speech noise (Qin & Oxenham, 2003).

2.2 BINAURAL HEARING

The term "binaural", as defined by Martin and Clark (2006), refers to the use of two ears for listening to acoustic stimuli. Thus, binaural hearing refers to the ability to use both ears in contrast to hearing with only one ear. It relies on interaural time differences, interaural level differences and interaural spectral differences which occur due to frequency shaping by the two pinnae (Beijen, Snik & Emmanuel, 2007). Binaural hearing is, therefore, dependent on the differences in the signals arriving at the two ears (Boothroyd, 2006).

Binaural hearing allows for better speech understanding in noise (Bronkhorst & Plomp, 1988; 1989) by allowing the listener to make use of the "cocktail speech" effect (Au, Hui & Wei, 2003). The "cocktail speech" effect occurs when the brain uses information from both ears to separate the sound sources. The listener is then able to selectively focus on the target speech, rather than the competing noise (Durrant & Lovrinic, 1995). Binaural hearing also allows for improved audibility and improved localisation abilities (Akeroyd, 2006; Galvin et al., 2007). Other subjective benefits are that the auditory signal sounds more natural, that listeners experience reduced listening effort and that they have improved quality of life (Offeciers et al., 2005). These improvements are generally ascribed to three effects present in normal hearing: (1) head shadow effect, (2) binaural summation effect and, (3) binaural squelch effect (Dillon, 2001).

2.2.1 Head Shadow effect

The head shadow effect, also known as the “better ear” effect (Akeroyd, 2006), is a physical event which occurs when sounds located on the far side of the head, are attenuated by the head and shoulders, so reducing the intensity of the sound when it reaches the opposite ear (Litovsky et al., 2004). The head and shoulders produce an acoustic barrier between the speaker’s voice and co-occurring noises, resulting in a better signal to noise ratio (SNR) at the ear closest to the speaker, thus making the speaker’s voice more audible (Gantz et al., 2002; Tyler, Dunn, Witt & Preece, 2003). The speaker’s voice and noise which typically arise from different locations arrive at each ear with small yet perceptibly different interaural time and intensity cues (Morera et al., 2005). The head shadow effect is frequency dependent and attenuates high frequency sounds much more than low frequency sounds due to the physical properties of the head, as well as the sound wavelength (Litovsky et al., 2004). Although two ears are not required to benefit from this effect, the listener will not be able to attend to the ear with the better SNR if the better ear has a hearing loss (Dunn, Tyler & Witt, 2005).

2.2.2 Binaural Summation

Binaural summation is the ability of the central auditory system to assimilate the auditory information received at each ear, thus improving auditory perception (Morera et al., 2005). When sounds are presented to the two ears, the sum of these sounds is perceived to be louder than the individual sounds (Durrant & Lovrinic, 1984). Because the brain processes redundant information from each ear, binaural summation may result in an improved threshold of approximately 3 dB (Tyler et al., 2003; Dunn et al., 2008), resulting in better speech perception performances in both quiet and noise (Dunn et al., 2005). This effect relies on the auditory signal arriving at the two ears simultaneously, with identical time and intensity cues at each ear (Morera et al., 2005). Since the same information is combined and coded twice, it is hypothesized that the resultant representation of the acoustic signal will be better than the original signal which arrived at each ear (Dunn et al., 2008).

2.2.3 Binaural Squelch

The binaural squelch effect is also called “release from masking” (Clark, 2003). This effect refers to the ability of the central auditory system to choose the ear with the better SNR when speech and noise arise from different locations. The differences in interaural time and intensity cues are identified and processed, resulting in improved separation of the speech and noise signals. Thus, the brain compares the different signals arriving at the ears and uses the waveform of the noise at the ear with the poorer SNR to partly cancel out the noise arriving at the ear with the better SNR (Moore, 1989; in Galvin et al., 2007). This, in turn, leads to improved speech perception of approximately 2-3 dB (Ching, van Wanrooy, Hill & Incerti, 2006).

2.2.4 Localisation

Localisation of the sound source is the ability to determine the correct location of the sounds in the environment (Galvin et al., 2007). It is a fundamental element of binaural hearing. Sound localisation is affected by the ability of the listener to use time, intensity and spectral differences in the sound arriving at the two ears (Tyler et al., 2003). It differs relative to the plane on which the sound occurs. Localisation on the horizontal plane involves the use of interaural time and phase differences, while localisation on the vertical plain is facilitated by spectral information (Mencher & Davis, 2006). Localisation of sound is important for attending to a selected speaker in the presence of interfering talkers and to avoid sources of danger (Seeber, Baumann & Fastl, 2004). It also plays a part in subjectively improving auditory experiences such as music appreciation (Tyler, Gantz et al., 2002).

2.3 SPEECH PERCEPTION

The perception of speech involves complex processing as speech is considered to be the most composite, purposeful and important auditory signal that one can attend to (Clark, 2003). Speech perception comprises of various levels of listening skills, namely detection, discrimination, identification, recognition and comprehension (Erber, 1982). Detection is the process whereby the listener becomes aware that he is listening to speech. Discrimination allows the listener to differentiate between speech alternatives.

Identification is the process whereby the listener is able to choose correctly from a finite set of words. Recognition involves identifying a speech utterance, without having any prior knowledge. Comprehension involves knowing the meaning of the word or utterances (Erber, 1982).

Speech perception abilities are not only affected by the person's hearing status, but also by the acoustic environment in which communication takes place. According to research, speech perception in noisy environments is aided by binaural cues such as; (a) interaural level differences, (b) interaural time differences, (c) fluctuations in competing voices and, (d) spectral differences between these voices and the target voice. In contrast, speech perception is negatively affected by (a) hearing impairment, (b) reverberation, (c) poor positioning of the listener relative to the speaker and, (d) the similarities between the speaker's voice and competing voices (Bronkhorst & Plomp, 1992).

According to Arsenault and Punch (1999), speech perception in competing background noise is considered to be the most common difficulty expressed by individuals with hearing impairments. This is understandable when one considers that both monaural and binaural processes are required to separate the target sound from other co-occurring sounds and/or noise (Culling, Hawley & Litovsky, 2004; Hawley, Litovsky & Colburn, 1999; Hawley, Litovsky & Culling, 2004) and individuals with hearing impairments may have compromised access to these processes. Arsenault and Punch (1999) reported that listeners with normal hearing displayed a 3.3dB SNR advantage over individuals with hearing impairment. This was attributed to the lesser ability of the subjects with hearing impairments to use head shadow cues (i.e. interaural level differences) and the binaural squelch effect. Bronkhorst and Plomp (1992) observed a similar binaural advantage (i.e. 3dB) when the performance of individuals with normal hearing and hearing impairment were compared. It was noted that even for listeners with normal hearing, speech recognition thresholds deteriorated as the number of competing signals increased. Performance was particularly affected when all the competing signals were presented from the front, and no binaural cues could be used. A further observation was that listeners with normal hearing were able to handle as many as six interfering talkers, from different positions, while listeners with hearing impairment experienced difficulties in situations where four interfering talkers were present.

Individuals with hearing loss obtain less benefit from fluctuations in competing noise than people with normal hearing (Feston & Plomp, 1990; Bronkhorst & Plomp, 1992). Various studies by Bronkhorst and Plomp (1988; 1989; 1992) reported that individuals with hearing impairment gained less advantage of the favourable SNR at the contralateral ear than normal hearing individuals. This decreased ability to adequately use the favourable SNR, seemed to be related to the degree of hearing loss present in the high frequencies. The SNR had to be 4.2-10dB better for the hearing impaired individuals to perform as well as the normal hearing individuals. Listeners with a symmetrical hearing loss displayed the same benefits for interaural time difference cues as those with normal hearing. Hearing impaired listeners, particularly those with high frequency hearing losses, benefited less from interaural level difference cues (Bronkhorst & Plomp, 1988). These benefits or lack thereof, however, can only be observed and quantified by conducting evaluations of speech perception abilities.

According to Clark (2003), the aim of speech perception tests is to assess the communication ability of listeners in typical communication settings. Tests of speech perception are, therefore, important as the results obtained are used to describe the hearing handicap rather than just the hearing thresholds (Clark, 2003). Furthermore, speech perception testing allows for the evaluation of the appropriateness of the assistive device and whether the device is programmed at the optimal settings. It also helps to identify the information, which is not being perceived by the individual, and provides information which will guide rehabilitation (Zwolan, 2000).

Several speech perception tests are currently available which attempt to evaluate various levels of listening skills. Various factors inherent to the testing procedure, including the test material, the presentation of this material, the response mode of the listener and the use of competing noise during testing, will affect the results obtained (Kirk, 2000). Tests which consist of sentences, such as the Bamford-Kowal-Bench Sentences (Bench, Kowal

& Bamford, 1979), are considered to be easier than tests consisting of words (Koch, 1999; in McConkey Robbins, 2000b). This can be attributed to a greater degree of redundancy present in sentences which enables the listener to interpret the message even if all the words in the sentence are not heard. Similarly, the identification of spondee words as required in the Children's Realistic Index for Speech Perception (Litovsky, 2003), is easier than the identification of monosyllabic words (Lee & van Hasselt, 2005), which is required in the Phonetically Balanced Kindergarten Word List (Haskins, 1949). In addition, open-set tasks such as the Phonetically Balanced Kindergarten Word List (Haskin, 1949) provide no contextual cues thus making it a more difficult task than closed-set tasks, such as the Children's Realistic Index for Speech Perception (Litovsky, 2003), which provides the listener with a set of options (Clark, 2003).

Further factors, inherent to the listener, may also play a role in the results obtained on speech perception measures. These include the age of the listeners, their speech perception abilities and their language levels (Kirk, 2000). Improved speech perception skills have been observed in children who receive their cochlear implants at early ages, with associated improvements in language development (McConkey Robbins, Svirsky & Miyamoto, 2000). According to Tyler, Tomblin, Spencer, Kelsay and Fryauf-Bertschy (2000), children who display elevated receptive and expressive language abilities on language tests, also display improved speech perception performance during evaluation. If all the factors which may affect speech perception abilities are considered, reliable comments can be made regarding the child's speech perception skills as well as the impact on language development, as the ability to integrate auditory information is an important skill for the development of representational language (Schopmeyer, Mellon, Dobaj & Niparko, 2000).

2.4 PERFORMANCE WITH HEARING AIDS

A hearing aid, as described by Staab and Lybarger (1994), is a device which amplifies sound, so that individuals with hearing impairments may use their residual hearing. Hearing aid technology has improved dramatically over the years, enabling individuals with hearing impairments to better utilize their residual hearing. Unlike analogue hearing aids, modern hearing aids use digital signal processing (DSP). They are able to reproduce the sound well and are programmed via the computer, thus ensuring more precise fittings (Stach, 1998).

The benefits of DSP include: more precise and flexible frequency shaping, acoustic feedback reduction and better noise reduction (Stach, 1998). Despite these benefits, current research has not been able to demonstrate that DSP has resulted in significant improvements of speech perception in noise. Furthermore, many hearing aid users report that the clarity of the sound is not necessarily improved with their hearing aids (Valente & Enrietto, 2002). This has a significant impact on speech understanding, particularly in noise.

Bilateral hearing aid fittings are generally prescribed for bilateral hearing losses as improvements in speech perception and localization has been noted with bilateral amplification (Byrne, 1981; Byrne, Noble & Le Page, 1992). This improved ability has been ascribed to the benefits of binaural effects, particularly the head shadow effect and binaural summation (Zurek, 1993; in Ching, Psarros, Hill, Dillon & Incerti, 2001). Martin and Clark (2006) therefore, recommend bilateral hearing aid fittings since the main objective of providing amplification is to restore auditory abilities to as close to normal as possible.

Although the majority of children with hearing impairment can benefit from conventional hearing aids, there are children with profound hearing loss who receive inadequate or no benefit from their hearing aids (Bess & Humes, 1995). According to Cole and Flexer (2007), inadequate amplification is associated with a speech recognition threshold (SRT) of 35 dB HL or worse. These children will therefore not develop spoken language or intelligible speech optimally because they do not receive sufficient amplification to perceive speech across the speech spectrum which has an average intensity level of 40 dB HL. According to Mueller and Grimes (1993), individuals with hearing thresholds of 30 to 40 dB HL at 3000 to 4000 Hz will have reduced speech perception capabilities as these frequencies are important for speech intelligibility. For these children, their only option is cochlear implants (O' Donoghue et al., 2000).

2.5 PERFORMANCE WITH UNILATERAL COCHLEAR IMPLANTS

With profound hearing impairment, due to a loss of hair cell function in the cochlea, neural impulses are not generated and electrical activity in the auditory nerve is not initiated. Cochlear implants differ from hearing aids because they directly stimulate the auditory nerve and bypass the dysfunctional cochlea, whereas hearing aids only amplify the sound, which then has to travel through the dysfunctional cochlea (Stach, 1998). The selection of the ear to receive a cochlear implant is an important decision. For unilateral cochlear implants, it is typically recommended that the better ear be implanted (van Hoesel, 2004). This decision, regarding the poor versus better ear, may be difficult to make on the basis of available pre-implant information such as hearing thresholds and performance on speech perception tests as this information may not be accurate in predicting which ear will perform better with a cochlear implant (Offeciers et al., 2005).

A unilateral cochlear implant is usually provided to a person who has a severe or profound bilateral hearing loss and does not demonstrate benefit from conventional hearing aids. Research by Geier, Barker, Fisher and Opie (1999) showed that unilateral cochlear implant users displayed improved speech recognition abilities postoperatively. Despite these improvements, difficulties associated with monaural hearing, have been reported by these cochlear implant users, particularly with speech understanding in noise and localizing the sound source (Byrne, 1980; in Ching, Incerti & Hill, 2004).

According to research by Nelson and Jin (2004) and Nelson, Jin, Carney and Nelson (2003), cochlear implant users display significant difficulties in situations involving fluctuating noise. They appear to have difficulty separating the speech and noise from each other. When speech signals are interrupted, they are unable to successfully integrate all the auditory information. The findings suggest that implant users are unable to use binaural summation and binaural squelch effects to aid speech perception in fluctuating listening conditions.

Due to the inability to separate sound sources, unilateral cochlear implant users do not have the advantage of using the "cocktail speech" effect since this is a binaural advantage (Au et al., 2003). Subjects with unilateral cochlear implants therefore required a SNR of at least +10 dB, while subjects with bilateral cochlear implants required a SNR of at least +5 dB to achieve discrimination scores which were comparable to those obtained in quiet.

The difficulties experienced in noise, by children with cochlear implants, are substantial when one considers that children generally spend large parts of the day in complex auditory environments (e.g. classrooms) where numerous sounds that differ in content and location occur simultaneously. These environments are filled with the voices of adults and children, as well as, environmental sounds and reverberation (Litovsky, 2005). These children are also typically placed in mainstream classrooms; where they are either partially or fully mainstreamed (Daya, Ashley, Gysin & Papsin, 2000; Picard & Bradley, 2001; Tobey, Geers, Rekart & Buckley, 2004). Researchers (Arnold & Canning, 1999; Bess, Sinclair & Riggs, 1984) have found classroom noise levels to range from 34 to 73 dBA. Bistafa and Bradley (2000) differentiate between "ideal" and "acceptable" levels for background noise in classrooms. The recommendations are 25 dB and 20 dB below the intensity of the speaker's voice for the "ideal" and "acceptable" levels respectively. In order to optimise speech perception abilities in difficult listening conditions, binaural hearing is considered to be necessary (Bronkhorst & Plomp, 1988; 1989).

2.6 PERFORMANCE WITH BIMODAL STIMULATION

Bimodal stimulation, as defined by Clark, Dooley and Blamey (1991; in Clark, 2003), occurs when an individual uses a cochlear implant on one ear and a conventional hearing aid in the other ear. In practice, this translates to the person receiving two different types of auditory stimulation; namely acoustic stimulation via the hearing aid and electrical stimulation via the cochlear implant (Morera et al., 2005). The person thus has to integrate the differing stimuli in order to benefit from this fitting arrangement.

In the past, cochlear implants were only fitted to persons who presented with bilateral severe-to-profound hearing losses and, who did not display any benefit from conventional amplification (NIH Consense statement, 1995; in Morera et al., 2005). Following cochlear implantation, the majority of these individuals ceased to use the hearing aid on the non-implanted ear as they did not perceive any benefit (Morera et al., 2005). As the criteria for cochlear implantation have become less stringent, many cochlear implant users now present with residual hearing in the non-implanted ear (Tyler, Parkinson et al., 2002). It is assumed that these unilateral cochlear implant users will benefit from potential binaural benefits if the residual hearing in the non-implanted ear up to 1000 Hz is aidable, and if the hearing aid is programmed according to the user's individual needs (Ching et al., 2004). With unilateral cochlear implants, amplification in the non-implanted ear is important to provide auditory stimulation so that speech recognition abilities do not deteriorate in that ear. It has been found that speech recognition abilities typically deteriorate in the unaided ear in individuals who have a bilateral hearing loss but are aided monaurally. This phenomenon has been ascribed to auditory deprivation (Silman, Silverman, Emmer & Gelfand, 1993).

Various studies have reported binaural benefits from bimodal stimulation, despite the fact that the two ears are receiving different auditory stimuli (Ching et al., 2001; Ching et al., 2004; Ching et al., 2006; Gifford, Dorman, McKarns & Spahr, 2007; Iwaki et al., 2004; Morera, et al., 2005). Tyler, Parkinson et al. (2002) found that the binaural advantage for speech perception in noise was observed when the speech and noise were in front of the listener (i.e. binaural summation effect), and when the speech was from the front and the noise was on the side closer to the cochlear implant (i.e. head shadow effect). When the noise occurred on the side of the hearing aid, no binaural benefit was observed. This was attributed to the inability of the ear with the hearing aid to take advantage of the head shadow effect (van Hoesel, Ramsden & O' Driscoll, 2002). Although, Dunn et al. (2005) reported listener benefits from bimodal stimulation, not all participants displayed this improved performance under bimodal conditions.

2.7 PERFORMANCE WITH BILATERAL COCHLEAR IMPLANTS

Reports indicate that bilateral cochlear implant users are able to take advantage of the binaural cues which normal hearing listeners use (Buss et al., 2008; Gantz et al., 2002; Laszig et al., 2004; Litovsky et al., 2004; Müller et al., 2002; Schleich, Nopp & D' Haese, 2004; Tyler, Gantz et al., 2002; Tyler et al., 2006; van Hoesel, 2004; van Hoesel, Böhm, Battmer, Beckschebe & Lenarz, 2005). These studies suggest that bilateral cochlear implantation allows the user to benefit from the head shadow effect, binaural summation effect and binaural squelch effect (Schleich et al., 2004; van Hoesel, 2004). Furthermore localisation is improved, thus bilateral cochlear implants allow the listener to locate the sound source, turn towards it, attend to the relevant signal and better cope with background noise than if they were implanted unilaterally (Laszig et al., 2004; Senn, Kompis, Vischer & Haeusler, 2005; Tyler, Gantz et al., 2002). Further benefits reported by individuals who have received bilateral cochlear implants include improved sound quality and reduced effort in listening activities, in their everyday lives (Litovsky et al., 2006; Offeciers et al., 2005; Wackym, Runge-Sameulson, Firszt, Alkaf & Burg, 2007). In addition to the measurable benefits of bilateral cochlear implants, other advantages also exist. One of these is that should one of the devices become faulty, the individual with bilateral cochlear implants will still have access to audition, via the unaffected implant (Bohnert, Spitzlei, Lippert & Keilmann, 2006). Furthermore, with two cochlear implants, the better ear will always be able to receive stimulation. Gantz et al. (2002) considers this to be an important advantage as there is currently no means of predicting which ear will perform better post-implantation. Also, with unilateral cochlear implants, the situation will always arise, in which the implanted ear is nearest to the noise, causing the cochlear implant user to experience great difficulty with speech understanding in noise.

It has been found that bilateral cochlear implant users experience a considerable benefit in speech perception in noise, bringing them closer to the performance of normal hearing individuals (Gantz et al., 2002; Litovsky et al., 2004; Müller et al., 2002; Ricketts et al., 2006; Schleich et al., 2004; Senn et al., 2005; Tyler, Gantz et al., 2002). A limitation of the study by Müller et al. (2002) was that the benefits experienced were expressed in terms of a 10dB SNR, rather than the gain in SRT. Some subjects therefore displayed limited or no benefits; because there was a ceiling effect as relatively high SNRs were needed. Although, the findings by Schleich et al. (2004) supported the findings that bilateral cochlear implant users benefit from binaural effects, their subjects did not show a statistically significant benefit from the squelch effect on the right side. A possible reason for this finding could be that the sample size was relatively small (21 subjects) and that there were great variations in duration of deafness, as well as, duration of cochlear implant use. Studies by other researchers have also supported the findings of binaural benefit (Dunn et al., 2008; Schön, Müller & Helms, 2002; van Hoesel et al., 2002; van Hoesel, Tong, Hollow & Clark, 1993; Wolfe et al., 2007).

Individuals obtained higher scores on speech perception tests when tested in quiet and in noise with bilateral cochlear implants as opposed to unilateral cochlear implants (Buss et al., 2008; Das & Buchman, 2005; Kühn-Inacker, Shehata-Dieler, Müller & Helms, 2004). Au et al. (2003) found that subjects with bilateral implants were better able to discriminate Cantonese lexical tones from background noise than subjects with unilateral cochlear implants. This better discrimination was attributed to the "cocktail party effect", whereby the brain used the information from both ears to separate the sound sources (Durrant & Lovrinic, 1995).

Research conducted by Müller et al. (2002) and Schön et al. (2002) suggested that the bilateral advantage experienced with bilateral cochlear implants does not seem to degrade over time, as performance on monosyllable tests remained relatively constant when tested at 1 month, 14 months, 45 months and at 52 months post implantation. The results also indicated that this binaural benefit is already present from 1 month post- second implant, if the user has at least 12 months of experience with his first implant (Müller et al., 2002). According to Schön et al. (2002), the subject's previous experience with a cochlear implant did not affect the reacquisition of binaural hearing, and all subjects displayed this soon after implantation, whether the implantations occurred sequentially or simultaneously. A lengthy training period is, therefore, not necessary for adults. Buss et al. (2008) reported similar findings whereby subjects showed improved performance with two cochlear implants relative to one, at various time periods, ranging from 1 month post-

second implant to 12 months. This research thus supports the finding that improvement in adults is noted as early as 1 month post-second implant.
Although all the studies showed bilateral benefit to some extent, the authors commented on the great variations that existed between the performance of the participants (Francis, Yeagle, Bowditch & Niparko, 2005; Galvin et al., 2007; Litovsky et al., 2006). Numerous studies therefore reported that some individuals, both adults and children, did not exhibit any bilateral benefit and that the participants did not necessarily perform better with bilateral cochlear implants relative to their performance with the better performing cochlear implant (Galvin et al., 2007; Schafer & Thibodeau, 2006; Scherf et al., 2007; Wackym et al., 2007). Furthermore, the time between the first cochlear implant and the second implant, as well as the age at first implantation did not seem to make a difference on the bilateral benefits obtained by children (Kühn-Inacker et al., 2004).

According to Ching et al. (2004), bilateral cochlear implants are justified in cases where patients do not receive adequate benefit from bimodal hearing. This may be the case with individuals whose hearing loss is so extreme that a hearing aid cannot adequately provide usable hearing (Tyler et al., 2003). Simultaneous bilateral cochlear implants are also regarded as the treatment of choice for children who have lost their hearing as a consequence of meningitis, due to the risk of cochlear ossification which may hinder the fitting of a second cochlear implant at a later stage (Baumgartner et al., 2004; Offeciers et al., 2005).

Even though bilateral cochlear implants have been shown to be beneficial, differences exist in the way normal binaural hearing occurs and the way in which sound is processed via the cochlear implant. Since normal binaural hearing uses subtle timing differences between the two ears, it would be difficult, if not impossible to achieve this timing of intra-aural electrical stimulation with two independently functioning implants (Tyler et al., 2003). The cochlear implant may therefore distort these intensity and timing cues, so affecting speech perception and localisation (Tyler et al., 2003). Cochlear implant users are also unable to use spectral and temporal cues introduced by the pinna, as the microphone for most speech processors is situated above the ear (Schleich et al., 2004).

It should also be remembered that inherent in the provision of a second cochlear implant is additional costs, surgical risks and time (Tyler et al., 2003). According to Brown and Balkany (2007), unilateral implantation is associated with a better risk-benefit ratio than bilateral cochlear implantation, especially when the second cochlear implant is implanted in a separate operation. The second implant thus carries the same surgical risks as the first implant but the benefit post-second implantation is not as tangible as with the first implant. A second issue is the cost of bilateral cochlear implants. With sequential implantation, the cost doubles, however, this does not translate into a similar increase in benefit (Brown & Balkany, 2007). From the research it can, therefore, be deduced that simultaneous bilateral implantation rather than sequential implantation is associated with better risk-benefit and cost-benefit ratios, as the need for a second operation (with the accompanying risks and costs) is eliminated. A cost-risk-benefit analysis should therefore be part of the decision making process when an individual is considered for bilateral implantation (Brown & Balkany, 2007; Tyler, Gantz et al., 2002).

A further concern with bilateral cochlear implants is that if better technology (e.g. technological superior device) or alternative treatment (e.g. stem cell therapy) becomes available in the future, the individual with bilateral implants would not be able to benefit from it as both ears would already have been implanted (Brown & Balkany, 2007; Tyler, Gantz et al., 2002). The person would then not be able to have further surgery to implant the newer devices. Although this risk exists, there have been a number of successful re-implantations, either to provide the individual with newer technology or to replace a defective implant (Tyler, Gantz et al., 2002). Furthermore, if one ear is conserved for better technology, particularly in children, the developing auditory system may be compromised as a result of auditory deprivation on the non-implanted side (Galvin et al., 2007).

Congenital, as well as, early onset hearing loss has a dramatic effect on the development of the auditory system. Even though these children may be provided with one cochlear implant, auditory deprivation is still likely to continue as the non-implanted ear may not be receiving any auditory input or inadequate input (Galvin et al., 2007). Auditory deprivation is typically a two-part process in children receiving bilateral cochlear implants sequentially. The initial stage of deprivation is bilateral and is due to the bilateral hearing loss, while the second stage is monaural and is due to the implantation of only one cochlear implant (Litovsky et al., 2006). A consequence of this unilateral stimulation may be that the auditory systems of these children are restructured, relative to the hearing loss. Reversal of this restructuring of the auditory pathways is not necessarily realized once the critical period in development has passed (Gordon et al., 2007). Currently there is limited information available regarding the extent to which these children can use the added benefits of binaural hearing, even if bilateral cochlear implants are provided. Since the paediatric cochlear implant population is relatively small and heterogeneous, a need for continued research, focusing on children with bilateral cochlear implants, has been identified.

When the costs and risks of providing bilateral cochlear implants are considered, it is imperative that the benefits of bilateral cochlear implants are measured and verified. The aim of the present study was to investigate speech recognition in children with bilateral cochlear implants. The findings of this study will allow evidence-based recommendations to be made to the families of children identified as being candidates for bilateral cochlear implants.

The methodology used in this study assessed speech recognition abilities of children with bilateral cochlear implants, in quiet and in noise, under bilateral and unilateral conditions. The present study did not aim to address other auditory skills associated with binaural hearing such as localisation. More specifically the research was aimed at finding answers to the following questions:

- How do cochlear implant users perform on speech recognition tasks with one cochlear implant as opposed to two implants, under various listening conditions?
- Are there differences in performance when the first cochlear implant as opposed to the second implant is being used?

- Is there a correlation between the length of cochlear implant use and the performance on speech recognition tasks?
- Do the findings support existing research?

CHAPTER 3: METHODOLOGY

The following section presents the aims, research design and participant selection criteria and procedure used in this study. Furthermore, the methods and procedures for both the data collection and methods of analyses are described.

3.1 AIMS

The main aim of this study was to compare the speech recognition of children fitted with bilateral cochlear implants, under binaural (BiCI) and monaural (CI 1 or CI 2 only) listening conditions, in quiet and in noise. Speech perception was selected as the area to be investigated, as Kirk (2000) states that speech perception measures are a means of obtaining tangible evidence of the benefit provided by cochlear implants

The specific aims of this study were:

1. To investigate the speech recognition of children utilizing one (unilateral) cochlear implant in quiet
2. To investigate the speech recognition of children, utilizing one (unilateral) cochlear implant in the presence of competing noise
3. To investigate the speech recognition of children utilizing two (bilateral) cochlear implants in the presence of competing noise
4. To determine whether a correlation existed between speech recognition abilities and duration of cochlear implant use
5. To compare performance on the CRISP, when using CI 2 in quiet, to performance on other speech perception measures

3.2 RESEARCH DESIGN

A quantitative experimental repeated measures research design was selected for this study as the aim of the study was to investigate the relationships which existed among the specified variables. As with quantitative research, the variables were separated (Leedy & Ormrod, 2001). The dependent variable under investigation, i.e., the effect observed as a consequence of the manipulation of the independent variables (Doehring, 2002), was the performance of the children on the speech recognition test as it reflected binaural benefit (i.e. binaural summation effect and head shadow effect). The independent variables, which were the variables being manipulated (Doehring, 2002), were the varying noise conditions (i.e. presence or absence of competing noise) and the various cochlear implant activation arrays (i.e. CI 1 activated, CI2 activated or both cochlear implants activated). The data collection entailed the use of consistent procedures across all the participants and test conditions and; statistical analyses were used to interpret the data (Leedy & Ormrod, 2001).

Due to the limited size of the population, this study utilized non-probability sampling, specifically the convenience sampling technique (Bailey, 1997). Participants were therefore, selected based on their availability and compliance to the selection criteria (Hegde, 2003).

Due to the relatively small size of the total population of children with bilateral cochlear implants, a repeated measures single subject research design was used, with each participant serving as his or her own control. This design was considered to be suitable as only a limited number of the total population of bilateral cochlear implant users met the selection criteria. Furthermore, this design is useful in studies which require the methodical and repeated measurements of a few individual cases (Hegde, 2003) as it accommodates for individual differences and does not regard these differences as errors. Thus the heterogeneity that typifies populations with specific communication disorders, such as hearing-impairment, is taken into account (Parkinson, 2003).

3.3 PARTICIPANTS

3.3.1 Participant selection criteria

All children in the Tygerberg Hospital / Stellenbosch University Cochlear Implant Programme, who met the following criteria, were included:

- Aged 3.5 years and older, as the CRISP test, utilized in the present study, was developed to test children aged 3.5 years and older (Litovsky, 2003).

- Used only oral communication, as literature (Dowell, Dettman, Blamey, Barker & Clark, 2002) indicated that the sole use of oral communication was associated with significantly better speech perception scores as opposed to children using a combination of oral and manual communication.
- Duration of profound deafness prior to the fitting of any type of amplification (including hearing aids) did not exceed 2 years, as children with less than two years of profound deafness displayed improved performance on speech perception tests relative to children with a longer duration of profound deafness (Dowell et al., 2002).
- Had their second CI activated at least 3 months prior to the study (Litovsky et al., 2004). This timeframe was selected, as previous studies have found that an improvement in performance for speech perception tests can be observed one month after activation of the second CI (Buss et al., 2008) and that 3 to 9 months experience with the second CI leads to further improvement in performance for spondee words (Litovsky, 2004).
- Participants who used either English or Afrikaans as their home language as the CRISP test is only available in these two South African languages.

The following children were excluded from the study:

- Children with additional disabilities, including developmental delays and intellectual disabilities. This exclusion criterion was included to ensure that performances were not due to any confounding variables caused by the disabilities, as children with developmental and cognitive delays were reported to show slower progress in speech perception abilities (Dowell et al., 2002).
- Children who were unfamiliar with the words used in the test, as reported by their parents/guardians. This exclusion criterion was included to ensure that the children's performances could not be attributed to poor vocabulary abilities, as the test used in the present study required the identification of words (Litovsky, 2003).

3.3.2 Participant selection procedure

After receiving permission to conduct this study, the coordinator of the Tygerberg Hospital / Stellenbosch University Cochlear Implant Programme assisted the researcher in identifying prospective participants. Seventeen children were identified as being prospective participants but only ten of these children were included in the study. Seven children were excluded. One suffered from autism and therefore did not meet the selection criteria. The remaining six children had been transferred to other Cochlear Implant programmes in South Africa as they did not reside in the Western Cape. Once it was established that the ten children met the selection criteria, their parents were approached regarding participation in the study. The parents and children were informed about the aims of the study, as well as the procedures involved. The researcher made sure that the parents and children understood what the study and participation therein entailed so that they could make informed decisions. Once the parents agreed to their child participating in the study, they were required to complete an Informed Consent form (see Appendices E and F). In addition to the parents consent, it was required that the child also agreed to participate in the study.

3.3.3 Participant description

Ten children attending the Tygerberg Hospital / Stellenbosch University Cochlear Implant Programme participated in this study. Five of these children used English as their home language and the other five participants used Afrikaans as their home language. The age range for the participants was from 5 years 7 months to 15 years 4 months, with a mean age of 9 years 5 months. All the participants had received their bilateral cochlear implants in two separate surgical procedures and used both cochlear implants consistently. All the participants used oral communication exclusively and had previously been enrolled in intensive auditory-oral programmes. In addition, all the participants attended mainstream schools.

The duration of profound deafness, prior to the fitting of any type of amplification (including hearing aids), as reported by the parents during the initial parental interview for possible cochlear implantation, did not exceed 2 years. The age of first implantation ranged from 7 months to 9 years 8 months, with a mean age of 2 years 11 months. The age at second implantation ranged from 2 years 5 months to 13 years 8 months, with a mean age of 7 years 3 months. The time between implants ranged from1 year 10 months to 7 years 3 months, with a mean delay of 4 years 4 months.

All participants were implanted with Nucleus cochlear implant systems bilaterally, as these are the systems currently being used in the Tygerberg Hospital / Stellenbosch University Cochlear Implant Programme. All the electrodes were programmed according to the individual's particular needs and all participants made use of the ACE coding strategy in both ears (see Table 3.1). Participants were instructed to set their devices according to the programmes and sensitivity settings which they were accustomed to. It was assumed that results obtained with these settings would be representative of performance in everyday communication settings (Ricketts et al., 2006).

Table 3.1: Description of Participants

Participant No.	Date of birth	Chronological age	Gender	Lang.	Aetiology	Age at diagnosis	Age: HA	Age: CI 1	Age: CI 2	Time delay CI1 and CI2	*LOU CI 1	*LOU CI 2	Ear CI 1	Ear CI 2	Model CI 1	Model CI 2	**CS CI 1
1	14/07/1991	15yr 4mo	M	Eng	Unknown: progressive	9mo	11mo	6yr 5mo	13yr 8mo	7yr 3mo	8yr 11mo	1yr 8mo	Left	Right	Esprit 3G	Esprit 3G	ACE
2	17/01/1997	9yr 6mo	F	Afr	Genetic	Birth	3mo	1yr 10mo	8yr 4mo	6yr 6mo	7yr 9mo	1yr 2mo	Right	Left	Esprit 3G	Freedom	ACE
3	27/10/1998	8yr 1mo	M	Afr	Meningitis	12mo	1yr 3mo	1yr 11mo	5yr 3mo	3yr 4mo	6yr 2mo	2yr 10mo	Left	Right	Esprit 3G	Esprit 3G	ACE
4	18/12/2000	5yr 7mo	F	Afr	Genetic	9mo	10mo	1yr 8mo	3yr 8mo	2yr 0mo	4yr 0mo	1yr 11mo	Right	Left	Esprit 3G	Esprit 3G	ACE
5	04/06/1997	9yr 6mo	F	Eng	Unknown	Birth	7mo	1yr 10mo	7yr 9mo	5yr 11mo	7yr 8mo	1yr 10mo	Left	Right	Esprit 3G	Esprit 3G	ACE
6	20/12/1992	14yr 0mo	M	Eng	Unknown	29mo	2yr 6mo	9yr 8mo	11yr 10mo	2yr 1mo	4yr 4mo	2yr 2mo	Right	Left	Esprit 3G	Esprit 3G	ACE
7	25/05/1996	10yr 3mo	M	Eng	Dandy Walker Syndrome	16mo	1yr 5mo	2yr 6mo	9yr 7mo	7yr 1mo	7yr 9mo	7mo	Right	Left	Esprit 3G	Esprit 3G	ACE
8	26/02/2001	5yr 10mo	M	Afr	Genetic	Birth	6wk	7mo	2yr 5mo	1yr 10mo	5yr 2mo	3yr 5mo	Right	Left	Freedom	Freedom	ACE
9	10/9/1999	7yr 3mo	M	Afr	Genetic	6mo	7mo	1yr 0mo	3yr 10mo	2 yr 10mo	6yr 4mo	3yr 5mo	Right	Left	Esprit 3G	Esprit 3G	ACE
10	17/06/1998	8yr 6mo	M	Eng	Genetic	Birth	10mo	2yr 1mo	6yr 6mo	4yr 5mo	6yr 4mo	2yr 0mo	Left	Right	Esprit 3G	Esprit 3G	ACE

Lang = mother tongue + language in which child was tested

**** LOU = Length of use*** *****CS = Coding strategy***

3.4 ETHICAL CONSIDERATIONS

Adhering to the ethical regulations of Stellenbosch University an approval of the research project was sought (see Appendix A) and obtained from the Committee for Human Research of the Faculty of Health Sciences (see Appendices B), permission for conducting the research was sought from the Medical Superintendent of Tygerberg Hospital (see Appendix C) and the coordinator of the Tygerberg Hospital / Stellenbosch University Cochlear Implant Programme (see Appendix D). The present study was only initiated once permission had been granted by these parties.

Informed consent was obtained from the parents of the participants and personal assent was obtained from each participant, after the following information, as required by the Declaration of Helsinki (World Medical Association, 1989; in Bailey, 1997), was provided:

- The purpose and aims of the study;
- The participant's role in the study;
- The test protocol and procedures to be followed;
- The manner in which confidentiality would be maintained;
- The voluntary nature of participation;
- The right to withdraw at any time;
- The use of the results;
- Dissemination of the results.

The above information was contained in the informed consent forms which were available in both English (see Appendix E) and Afrikaans (see Appendix F), depending on the home language of the participant. The informed consent form followed the format obtained from the Council for Health Research, Stellenbosch University.

3.5 TESTING PARAMETERS

3.5.1 Testers:

The researcher, who had 8 years of clinical experience in Audiology, conducted all the testing, with the aid of a co-tester. The co-tester was an audiologist, who had 21 years of clinical experience in the area of cochlear implants. The role of the co-tester included assisting with the setting-up of the equipment, testing of the children and recording of the responses obtained from the participants. She was also required to repeat the responses in order for the tester to accurately record it on the response forms.

3.5.2 Instrumentation and Materials:

3.5.2.1 Audiometer

All tests were conducted on the GSI 61 clinical audiometer (serial number: 0772), which had been calibrated a minimum of 6 months prior to testing by a trained technician, according to the specifications set out by the manufacturer.

3.5.2.2 Speakers

The audiometer was connected to 3 speakers, which were mounted onto stands and were positioned at 0° azimuth, 90° azimuth and 270° azimuth (Litovsky, 2003; 2005). This speaker configuration allowed the tester to present the target sound from the front speaker and the multi-talker babble from the front, left and right side of the participant. The speakers had been calibrated by a trained technician, at least six months prior to testing, according to the requirements of the Tygerberg Hospital / Stellenbosch University Cochlear Implant Programme and the specifications as set out by the manufacturer.

3.5.2.3 Test Environment

All testing was conducted in the same carpeted sound-proof room, measuring 3.5m by 2.8m., in the Speech and Hearing Clinic, Tygerberg Hospital. This measure was taken to avoid differences in the performance of the participants due to differences in room acoustics. A chair was positioned so that the distance between the participant's head and speakers was 1m (Laszig et al., 2004; Litovsky, 2003; Schafer & Thibodeau, 2006).

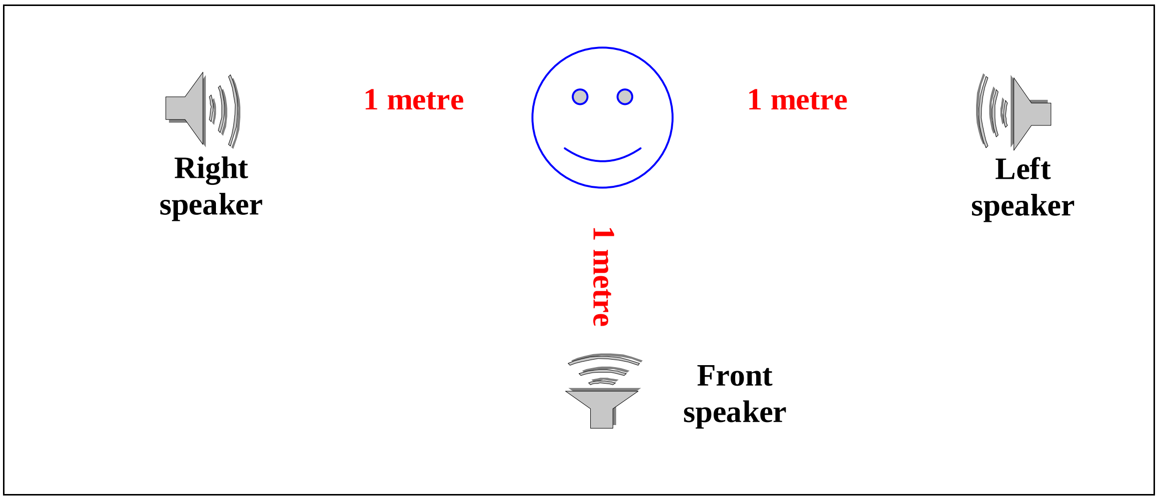


Figure 3.1: Graphic representation of testing array

3.5.2.4 Test

The Children's Realistic Index for Speech Perception (CRISP), South African Version (Muller, 2004), was used as the speech perception measure. This test version is based on the original CRISP developed by Ruth Litovsky (2003). This particular test was selected, as according to the researcher's knowledge, it is the only test which was specifically developed to test speech perception abilities, in noise, in young children with bilateral cochlear implants. The CRISP tests children's abilities to recognise spondee words (e.g. toothbrush, ice-cream and bathtub). It is a closed set test, designed for use in the free field. The testing conditions are intended to simulate complex listening situations for children from the age of 3.5 years. The test contains: (a) Disc 1, which contains 20 lists of target words / spondees, spoken by a South African male; (b) Disc 2, which contains the competing sentences / multi-talker babble, spoken by 2 females; (c) an instruction manual and; (d) a book, which contains the stimulus pictures – each page shows the target word and three other pictures (Litovsky, 2003).

The South African version of the CRISP is available in both English and Afrikaans. In both these versions, the target words are spoken by a South African male. This modification was made to minimise the influence of an unfamiliar accent on the speech recognition scores obtained by the children. Furthermore, words which were not culturally representative of South Africa (e.g. cowboy and barnyard) were omitted from the English version. The Afrikaans version of the CRISP consists of spondee words which were selected based on the semantic repertoire of a typically developing 4 year old (Mrs A.M. Muller, personal communication, November 10, 2008). In addition, only words which could be represented pictorially were included.

The CRISP test was designed based on the principles recommended for children's test material. The vocabulary level of the test is, therefore, well-defined and appropriate for the specified age range (Stach, 1998). Decreased performance can thus be ascribed to the hearing disorder rather than to a language disorder. It is a closed-set test which allows for the child to select the correct response from a limited set of options (Stach, 1998). Closed-set tests are useful with children, particularly those with hearing impairments, as they may not have the necessary language skills to complete an open-set task. Further advantages of using this type of test are that responses can be obtained from children who are too shy to speak; and that errors in scoring, which may arise from the audiologist's inability to effectively understand the child's speech, are reduced (Northern & Downs, 2002). A disadvantage of using a closed-set test is that the child's correct response could be due to chance, depending on the amount of foils which are provided (Tye-Murray, 1998). Since four stimulus pictures are provided, the CRISP has a chance score of 25%.

The use of single words in the CRISP does not provide contextual information that would normally be available to a listener (Mencher & Davis, 2006). However, the use of spondee words provides a degree of extrinsic redundancy which is useful when interpreting the test results. The extrinsic redundancy present in the test material limits the impact of the hearing loss on the test results, thus the performance on the test reflects the perceptual skills, rather than the hearing loss (Stach, 1998).

The stimulus tracks (both target words and multi-talker babble) were played via a Hewlett Packard Laptop computer (serial number: PP2190), using a Creative Sound Blaster digital-signal processing sound card (serial number: AM01303220000820). The level of the stimuli was controlled by means of the audiometer.

3.6 DATA COLLECTION PROCEDURE

3.6.1 Review of Participants' records

The review of the participants' records, as compiled by the Tygerberg Hospital / Stellenbosch University Cochlear Implant Programme, allowed the researcher to obtain the following information, of which most appear in Table 3.1:

- Date of birth
- Age at diagnosis
- Aetiology of hearing impairment
- Age at initial hearing aid fitting
- Age at first cochlear implantation
- Ear which received the first / second cochlear implant (right / left)
- Age at second cochlear implantation
- Model of speech processor
- Coding strategy
- Time between first and second cochlear implant
- The pre-implant aided thresholds (where available, see Appendix I)
- The most recent aided thresholds (unilateral), if these were not obtained on the day of testing (see Appendix I)
- Results of previous speech recognition tests which had been performed within 1 year of the testing date (see Figure 4.13, p. 62). These tests included the
    - Phonetically Balanced Kindergarten (PBK) Words (Haskins, 1949); which consists of 3 word lists of 50 words each.
    - Bench-Kowal-Bamford (BKB) Sentence Test (Bench, Kowal & Bamford, 1979); which consists of 20 lists of sentences containing 50 key words, i.e. 3 to 4 words per sentence.
    - Ouditiewe Diskriminasie Prent Identifikasie (ODPI) (Muller, 1978) which is an Afrikaans adaptation of the Word Intelligibility Picture Identification test (Ross & Lerman, 1970).

Information with regards to date of birth, age of diagnosis and age at initial hearing aid fitting were obtained from the record of the first parent interview, which had been conducted to determine the participant's candidacy for the initial cochlear implant.

3.6.2 Pretest Procedures:

The children's cochlear implants and batteries were checked before the commencement of testing to ensure that these were functional during the testing procedure. Where necessary, batteries were replaced. However, most of the children were able to report faults promptly as they were experienced cochlear implant users.

Aided thresholds (unilateral) were obtained immediately prior to testing for those participants who had not visited the Tygerberg Hospital / Stellenbosch University Cochlear Implant Programme recently (i.e. within the same week as the testing). The thresholds were tested using warble tones at frequencies ranging from 250Hz – 4000Hz as per the protocol of the Cochlear Implant Programme. The average PTAs for the participants were 25 dB HL with the first cochlear implant and 26 dB HL with the second implant (see Appendix I).

3.6.3 The CRISP TEST:

Participants were tested in the following conditions:

Table 3.2: Description of listening conditions

Listening conditions		CI activated	Target Source (azimuth)	Source of competing noise (azimuth)
A	Quiet – unilateral	First cochlear implant (CI 1)	Front (0°)	None
B	Front – unilateral	First cochlear implant (CI 1)	Front (0°)	Front (0°)
C	Ipsilateral to CI 1 – unilateral	First cochlear implant (CI 1)	Front (0°)	Right/Left (90 °/270 °) - depending on ear implanted first
D	Quiet – unilateral	Second cochlear implant (CI 2)	Front (0°)	None
E	Front – unilateral	Second cochlear implant (CI 2)	Front (0°)	Front (0°)
F	Ipsilateral to CI 2 – unilateral	Second cochlear implant (CI 2)	Front (0°)	Right/Left (90 °/270 °) - depending on ear implanted second
G	Front – bilateral	Both implants (BiCI)	Front (0°)	Front (0°)
H	Ipsilateral to CI 1 – bilateral	Both implants (BiCI)	Front (0°)	Right/Left (90 °/270 °) – depending on ear implanted first

The listening conditions were defined according to the location of the competing noise (multi-talker babble). The conditions were presented in the same order to all the participants. Thus, the same word list was presented to each participant under the same listening condition. This measure was taken to facilitate comparison of performance across the listening conditions. Random presentation of the word lists was not deemed to be necessary as all the word lists contained the same stimulus words, although the order of presentation differed between lists. The sound source for the target voice was constant at 0° azimuth for all test conditions, while the source of the competing noise varied, depending on the test condition. The ear, which was implanted first, was selected for the unilateral conditions as it was assumed that performance would be better with this implant. Reasons for this assumption included that the children had more experience listening with that particular ear and that the ear had experienced a shorter duration of auditory deprivation (Senn et al., 2005).

The following test protocol was followed (Litovsky, 2003):

3.6.3.1 ***Pretest procedures:***

Initially, the VU metre was calibrated, using Track 1 (calibration tone) on CD1. This was done to ensure that the tones were presented at the appropriate levels, as reflected on the audiometer. The stimulus was calibrated using a Rion sound level meter (model: NA-14, serial number: 11024331) placed at the level of the participant's head.

The participant was then familiarized with the test activity, pictures and target voice, using the familiarisation track of the CRISP. This was done to ensure that the participant's performance was not influenced by poor understanding of the activity and unfamiliarity with the vocabulary used.

3.6.3.2 ***Instructions to participant:***

Each participant was given the same instructions: "Listen to the man, not to the lady. You must point to the picture that matches the word that you heard the man say. If you are not sure what was said, try and guess the word. "

3.6.3.3 ***Test procedure:***

The participant was placed in the sound proof room and asked to sit on the chair. Once seated, the tester verified that the distance between the speakers and participant's head was 1 metre (see Figure 3.1). This was done by measuring the distance between the speakers and participant's head, using a measuring tape. The co-tester sat next to the child and held the book containing the stimulus pictures.

The test instructions were given and the participant was required to switch off CI 2. The participant was shown a single page containing four pictures, each representing a specific spondee word. A recording of the word was presented and the participant was requested to point to the picture that corresponded to the spoken word. Once the participant had pointed to the picture, the co-tester verbally named the picture that had been identified to enable the tester to record the response. All the participant's responses were recorded by the tester on the response forms (see Appendices G1-G8 for English forms and H1-H8 for

Afrikaans forms). The testing procedure was repeated until a list of twenty words (20 pages) had been presented.

A complete list of words was presented in English or Afrikaans, depending on the child's home language, for each of the first 3 listening conditions (see Table 3.2): A (List 1, see Appendices G1 and H1), B (List 2, see Appendices G2 and H2) and C (List 3, see Appendices G3 and H3). The participant was then instructed to switch on CI 2 and switch off CI 1. A complete list of words was presented for each of the next 3 listening conditions (see Table 3.2): D (List 4, see Appendices G4 and H4), E (List 5, see Appendices G5 and H5) and F (List 6, see Appendices G6 and H6).

Lastly, the participant was instructed to switch on CI 1 and was tested with both cochlear implants activated. A complete list of words was presented for each remaining 2 listening conditions (see Table 3.2): G (List 7, see Appendices G7 and H7) and H (List 8, see Appendices G8 and H8). Testing in quiet, under binaural listening conditions, were not included in this study as all the participants had performed close to the ceiling in the unilateral (CI 1) condition.

A total of 8 word lists (150 words) were presented to each participant, covering the various noise conditions and cochlear implant arrays (see Table 3.2). The participants received no feedback about their performance, which was scored in terms of the number of target words correctly identified.

The test procedure and scoring criteria were kept constant for all the test conditions. No visual cues, specifically lip-reading and sign language, were made available to the participants. Testing for each condition took between three and five minutes, depending on the age of the child and the testing condition. All the participants were given rest breaks as needed (Schafer & Thibodeau, 2006). This was done to prevent fatigue, which could possibly have affected the participants' performances and thus affect the reliability of the study (Bailey, 1997).

In conditions containing the competing noise sound, the noise was activated first, followed by the target sound. The competing noise was turned off approximately 1-2 seconds after the target sound had been completed.

The target stimuli, which were produced by a white South African male, were played at an intensity of 60dB HL (as reflected on the audiometer) which was equivalent to 70dB SPL, as measured on the sound level meter (Francis et al., 2005; Gantz et al., 2002; van Hoesel et al., 2002). 70 dB SPL is generally the intensity level associated with speech perception tests (Zwolan, 2000). The multi-talker babble, which utilized two white South African female voices, was played at an intensity of 55dB HL, as indicated on the audiometer. The intensities of both the target sound and the multi-talker babble were kept constant. The fixed signal-to-noise ratio (SNR) of +5 dB was selected as Au et al. (2003) reported that a SNR of + 5 dB is required to achieve discrimination scores with bilateral cochlear implants which are comparable to the best discrimination scores achieved in a quiet environment.

3.7 DATA ANALYSIS

The study utilized both visual means of data presentation and statistical analysis methods. Single-participant designs usually use visual analysis as the results are easily discernible, when presented graphically. Statistical analysis methods were used to supplement the visual analysis as the treatment effects were not large for all the participants (Doehring, 2002).

Raw scores (with a maximum of 25) were obtained for each of the 8 listening conditions (see Table 3.2). A raw score equal to 80% was regarded as good performance on the test, as this percentage was considered to correspond to the speech reception threshold which would have been obtained, if an adaptive tracking method rather than a fixed signal to noise ratio was used (Litovsky et al., 2004; Parkinson, 2003).

The results of the two speech perception tests (BKB and PKB words), which were obtained from the review of the participants' records, were calculated as a score out of a maximum of 50. These scores were converted to raw scores out of 25 to facilitate comparison with the scores obtained on the CRISP test, which is scored out of a maximum of 25. Only after these scores had been converted, were the results used for the purpose of statistical analysis. The results of the remaining test (ODPI) were not adjusted as it was scored out of a maximum of 25.

All statistical analyses in this research study were performed using a computer-based statistical programme, *Statistica 7.0* (StatSoft Inc., 2004). Statistical analysis of data was done using both parametric and non-parametric statistics. The parametric statistics were initially used, but the analyses were repeated non-parametrically, as these methods are better suited for studies involving small samples, where a normal distribution cannot be assumed (Munro, 2005). These non-parametric methods are also applied, when research participants serve as their own controls or when a repeated measures design is used (Munro, 2005), as in this study.

The Friedman matched samples analysis was utilized to compare the participants' performance under the listening conditions B, E and G; as well as C, F and H (see Table 3.2). Comparisons between performance under listening conditions A and D (see Table 3.2) were made using the Wilcoxon matched pairs test. These non-parametric tests were selected as the residuals were not normally distributed (Munro, 2005).

A regression analysis was utilized during the statistical analysis of the raw data to establish whether a correlation existed between the participants' performances and the length of use of the respective cochlear implants. Regression is typically used to make predictions about one event, based on another (Munro, 2005).

3.8 RELIABILITY AND VALIDITY:

For this particular study, *triangulation* was used as the main method for increasing the level of validity and reliability. Reliability as defined by Neuman (2003) relates to the consistency of the results, when the study is repeated. Validity relates to how well the constructs being measured are reflected in the definition and methods of measurement.

Triangulation, occurs when the desired phenomena is examined from various angles (Neuman, 2003). Although several types of *triangulation* are described in the literature, for the purpose of this study, *triangulation of observers* and *triangulation of theory* was used (Neuman, 2003). Thus all participants were tested by a tester and co-tester, who both verified all responses before these were recorded. Furthermore, the methodology and results of this study were compared to previous literature, performed by different researchers, using different techniques.

A further method of increasing the reliability entailed formulating clear definitions of the constructs under examination (Neuman, 2003). The use of a pre-existing test further added to the validity of this study (Bailey, 1997).

Validity and reliability was thus increased by formulating clearly defined and organized constructs, using a co-tester, using a pre-existing test and by the comparison and concurrence of these results with existing literature.

CHAPTER 4: RESULTS AND DISCUSSION

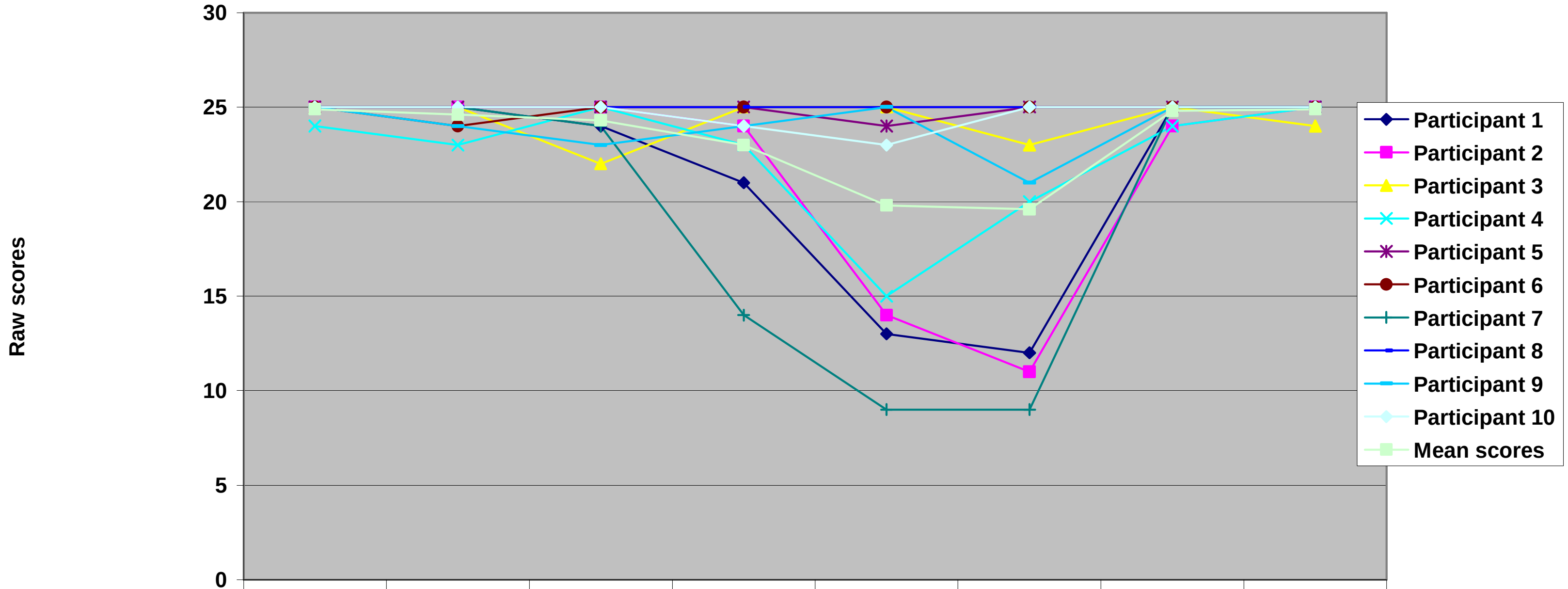
The overall aim of this study was to compare the speech recognition of children fitted with bilateral cochlear implants, when they were using one or both implants in quiet and in noise. The results discussed in this section are based on the data from the 10 participants. Due to the small size and specialized nature of the population only 10 participants could be found for the study. The results will be presented in the order of the specific aims of the study. In all the statistical analyses a significance level of $\propto$ = 0.05 (i.e. 5 %) was used. A raw score equal to 80% was regarded as good performance on the test, as this percentage was considered to correspond to the speech reception threshold which would have been obtained if an adaptive tracking method rather than a fixed signal to noise ratio was used (Litovsky et al., 2004; Parkinson, 2003).

In order to facilitate the discussion, a brief overview of the listening conditions is included below:

Table 4.1: Overview of listening conditions

Condition	Cochlear Implant activated	Binaural effect
A	CI 1 activated in the absence of noise	None
B	CI 1 activated with noise source located at the front	None
C	CI 1 activated with noise source located ipsilateral to CI 1	None*
D	CI 2 activated in the absence of noise	None
E	CI 2 activated with noise source located at the front	None
F	CI 2 activated with noise source located ipsilateral to CI 2	None*
G	Both CIs (BiCI) activated with noise source located at the front	Binaural summation effect
H	Both CIs (BiCI) activated with noise source located ipsilateral to CI 1	Head shadow effect

* The head shadow effect may be examined by presenting the noise ipsilateral to the test ear (Schafer, Amlani, Seibold & Shattuck, 2007). However, for purposes of this study, binaural effects were only considered for listening conditions in which both CIs were activated, as the listener was unable to hear the speech signal in the ear in which the cochlear implant had been deactivated in the unilateral listening conditions.



Listening conditions	A	B	C	D	E	F	G	H
Participant 1	25	25	24	21	13	12	25	25
Participant 2	25	25	25	24	14	11	24	25
Participant 3	25	25	22	25	25	23	25	24
Participant 4	24	23	25	23	15	20	24	25
Participant 5	25	25	25	25	24	25	25	25
Participant 6	25	24	25	25	25	25	25	25
Participant 7	25	25	24	14	9	9	25	25
Participant 8	25	25	25	25	25	25	25	25
Participant 9	25	24	23	24	25	21	25	25
Participant 10	25	25	25	24	23	25	25	25
Mean scores	24.9	24.6	24.3	23	19.8	19.6	24.8	24.9

Figure 4.1: CRISP results of each participant under various listening conditions

Figure 4.1 is a graphic representation of the results obtained on the CRISP test by the individual participants (1-10), for each listening condition (see Table 4.1). The actual scores obtained by the participants are included in Figure 4.1.

4.1 SPEECH RECOGNITION IN QUIET

The first sub-aim was to investigate the speech recognition of the participants while using one cochlear implant, in quiet. This was achieved by testing each participant in the absence of competing noise while; (a) using CI 1 only (listening condition A; see Table 4.1) and (b) using CI 2 only (listening condition D; see Table 4.1).

4.1.1 Performance with CI 1

The mean score for listening condition A, where only the first cochlear implant was used, was 24.9 out of a maximum score of 25, with a range from 24 to 25. Nine of the participants obtained the maximum score of 25, while one participant obtained a score of 24. All the participants achieved high scores when using their first cochlear implant in the quiet condition (see Figure 4.1).

These results were expected as all the participants were considered to be good performers with their first cochlear implant, prior to the implantation of the second cochlear implant (see Appendix I – Speech Perception Category). As the participants in this study were tested with only one CI activated, for all practical purposes they presented with unilateral hearing losses, thus these results correlate to those reported by Ruscetta, Arjmand and Pratt (2005) who found that children with unilateral hearing losses performed well when the target signal was located at 0º azimuth. These results correlate with those reported by Gantz et al. (2002) and Morera et al. (2005), who attributed the high scores obtained to a ceiling effect.

Furthermore, due to improvements in technology, speech perception by unilateral cochlear implant users have improved significantly and average scores of 70% to 80% are typically reported for speech perception in quiet (Stickney, Zeng, Litovsky & Assmann, 2004). According to O'Donoghue et al. (2000), better speech perception abilities with one cochlear implant was associated with early age of implantation, as well as, the communication approach of the child. Most of the participants in the present study received their first cochlear implants at a young age (before 3 years of age) and all of the participants used oral language as their only means of communication. The two participants (participant 1 and participant 6) who were not implanted at an early age had previously benefited from hearing aids. Of these two participants, one (participant 1) suffered from a progressive hearing loss and had only been implanted after his hearing had deteriorated and he no longer benefited from his hearing aids. The literature reported that substantial improvements in speech perception abilities were observed in the first three to fours years post implantation (Dowell et al., 2002) and could still be observed 5 years post implantation (O' Donoghue et al., 2000). All the participants had been using CI 1 for 4 years or longer at the time of the testing, thus good performance on the speech recognition tests were expected, as they had already acquired significant speech perception skills over this long period of cochlear implant use (see Appendix I – Speech Perception Category).

Using their CI 1, all the participants presented with 3-frequency Pure Tone Averages (PTAs) ranging from 20 to 33 dB HL, with a mean PTA of 24 dB HL (see Appendix I). Considering these hearing levels, the high scores obtained with the first cochlear implant in quiet are expected, as literature suggests that a positive correlation exists between PTAs and the successful use of cochlear implants. According to Manrique, Cervera-Paz, Huarte and Molina (2004), children who are successful cochlear implant users typically present with post-operative PTAs of less than 40 dB HL, as this hearing level is considered to be the dividing line between efficient and non-efficient social interaction.

4.1.2 Performance with CI 2

The raw scores obtained for listening condition D, where only the second cochlear implant was used, ranged from 14-25 (see Figure 4.1). The mean score was 23. Four of the participants (participants 3, 5, 6, and 8) obtained the maximum score of 25. Another five participants (participants 1, 2, 4, 9 and 10) obtained 80 % or more, while only one participant (participant 7) obtained a relatively low score of 14. It should be noted that the participant who obtained the lowest score was also the only one who had been using his second implant for less than 12 months (i.e. 7 months). These findings are consistent with those reported by Peters, Litovsky, Parkinson and Lake (2007), who found that children displayed significant improvements in performance with their second cochlear implant during the first 12 months, thus it would be expected that children who were using CI 2 for longer than 12 months would obtain better scores.

Using their CI 2, the participants presented with 3-frequency PTAs ranging from 23 to 35 dB HL, with a mean PTA of 26 dB HL (see Appendix I). As all of the participants had PTAs of less than 40 dB HL with CI 2, they could be considered to be successful cochlear implant users (Manrique et al., 2004). However, participant 7 performed poorly with CI 2 despite having a PTA below 40 dB HL. According to Bohnert et al. (2006), individuals with similar hearing levels do not necessarily perform identically on speech perception tests as other factors (e.g. the delay between CI 1 and CI 2) may also affect performance. The poor performance of participant 7 when using CI 2 can, therefore, probably be attributed to the fact that he was using his cochlear implant for less than 12 months and could therefore still show further improvement (Peters et al., 2007).

4.1.3 Comparison between performance with CI 1 and CI 2

Despite the average performance being better (1.9 points, see Figure 4.1) under listening condition A than listening condition D, a repeated measures Analysis of Variance (ANOVA) showed that this difference was not significant ($p = 0.11$). Since the residuals were not normally distributed, the analysis was repeated using the non-parametric Wilcoxon Matched Pairs Test (Munro, 2005) which indicated that the difference was indeed significant ($p = 0.027$).

The participants thus performed better when using their first cochlear implant as opposed to using their second implant. These findings are similar to those reported by Buss et al. (2008), Laszig et al. (2004) and Scherf et al. (2007) in which the better ear performed significantly better than the poorer ear. A major difference between those studies and the present study is that the participant pool in the Laszig et al. (2004) study included participants who had received their cochlear implants simultaneously and sequentially. Furthermore, the participants in the study by Buss et al. (2008) were individuals who had received their bilateral cochlear implants simultaneously, while the present study only included participants who had received their implants sequentially. Thus, for those particular studies, the definition of better ear is not necessarily the first implanted ear. A possible explanation for the findings of the present study is that the participants were using their first cochlear implant for a much longer time than their second cochlear implant and had, therefore, gained more experience with the first implant. Furthermore, the period of auditory deprivation was typically longer for the second ear (Senn et al., 2005). Studies by Peters, Litovsky, Lake and Parkinson (2004) and Peters et al. (2007) found that although children aged 8 years 1 month to 13 years showed improvement in speech perception abilities with CI 2, even after 12 months of use, performance with CI 2 was still significantly poorer than performance with CI 1. In the present study, 8 of the participants were within this age range or older, thus the findings of the present study support these findings as reported by Peters et al. (2004; 2007). An additional factor may be that all the participants who were selected for the present study had acquired good speech perception capabilities with their first cochlear implant (see Appendix I) prior to being implanted with the second implant; therefore, higher scores could be expected with that particular ear.

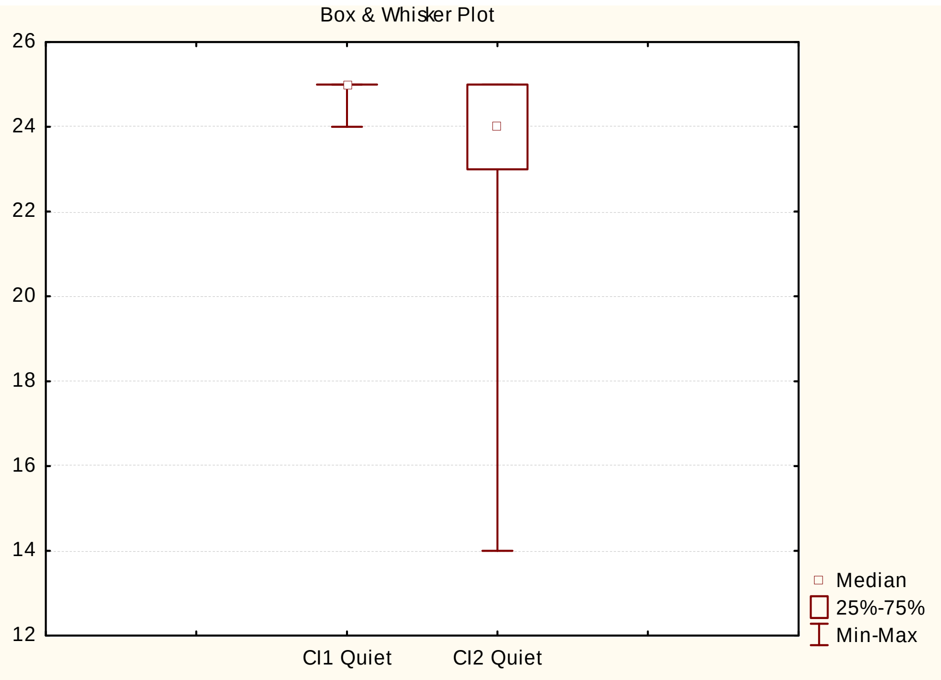


Figure 4.2: Comparison between listening conditions A (CI 1) and D (CI 2)

Visual inspection of Figure 4.2 reveals that there were greater variations in raw scores, when the participants were using their second cochlear implant than their first implant. These variations were possibly due to the fact that the participants had been using their second cochlear implants for shorter durations than their first implants and had probably not acclimatized fully to auditory stimulation in that ear (Senn et al., 2005). Within the pool of participants, variations in the length of use for both the first and second cochlear implants existed. It is expected that variations in length of use of the second cochlear implant would have a greater effect on the findings than variations in length of use of the first implant as all the participants had been using their first cochlear implants for 4 years and longer, while the duration of use of the second cochlear implant for all participants was less than 4 years. Research indicates that speech perception performance shows significant improvement during the first 3 to 4 years (Dowell et al., 2002) or even up until about 5 years post-implantation (O' Donoghue et al., 2000), thus maximum performance can be expected after this period.

Variations in the performance of the participants may also be related to the duration of deafness of the second ear. A criterion for inclusion in the study was that the duration of profound deafness prior to the implantation of CI 1 had to be no longer than 2 years. However, duration of deafness for the second ear was not specified. Findings reported by Wolfe et al. (2007) indicate that speech recognition in quiet, with CI 2, is affected by the duration of deafness of the second ear. According to their study, speech perception in quiet was better for those participants who received their second cochlear implant before 4 years of deafness of the second ear. Within, this particular study, the participants who scored the least with CI 2 (participants 1 and 7) received their second cochlear implants more than 7 years after receiving their first implant.

4.2 SPEECH RECOGNITION IN THE PRESENCE OF COMPETING NOISE

Both the second and third sub-aims were related to speech recognition in noise and are thus discussed together under this heading.

The second sub-aim was to investigate the speech recognition of the participants while using one cochlear implant (unilateral), in the presence of competing noise. The participants were tested while using each cochlear implant separately. Each participant was tested in the presence of competing noise located at the front (0° azimuth) of the participant (listening conditions B and E, see Table 4.1), ipsilateral to the first cochlear implant (listening condition C, see Table 4.1) and ipsilateral to the second cochlear implant (listening condition F, see Table 4.1).

The third sub-aim was to investigate the speech recognition of the participants while using both cochlear implants (BiCI), in the presence of competing noise. This was achieved by testing each participant in the presence of competing noise located at the front of the participant (listening condition G, see Table 4.1) and ipsilateral to the first cochlear implant (listening condition H, see Table 4.1).

4.2.1 Competing noise located at 0° azimuth (front)

An improvement in performance while being tested under listening condition G, relative to listening conditions B and E, was considered to be an indication of binaural summation. According to Schafer et al. (2007), binaural summation is typically investigated by presenting both the speech and noise through the same speaker, which is located at 0° azimuth.

4.2.1.1 Performance with CI 1

The mean score for listening condition B, where only the first cochlear implant was used, was 24.6 out of a maximum of 25. The participants' scores ranged from 23-25 (see Figure 4.1). Seven of the participants (participants 1, 2, 3, 5, 7, 8, 10) obtained the maximum score of 25, while the other 3 participants (participants 4, 6 and 9) obtained above 80% (see Figure 4.1).

4.2.1.2 Performance with CI 2

The mean score for listening condition E, where only the second cochlear implant was used, was 19.8 with a range from 9-25 (see Figure 4.1). Four participants (participant 3, 6, 8 and 9) obtained the maximum score of 25, while 2 participants (participants 5 and 10) obtained more than 80%. The other four participants (participants 1, 2, 4, 7) obtained scores ranging from 9-15 (see Figure 4.1). Three of the participants (participants 1, 2 and 7) who obtained lower scores, were older than 8 years 1 month. Peters et al. (2004; 2007) previously reported that children who were older than this age typically performed poorer with their second cochlear implant than their first cochlear implant, even after 1 year post-implantation.

4.2.1.3 Performance with BiCI

The raw scores obtained for listening condition G, where both cochlear implants were used, ranged from 24-25, with a mean score of 24.8 (see Figure 4.1). Only participants 2 and 4, with raw scores of 24, obtained less than the maximum of 25. The lack of observable improvement under this listening condition may be attributed to a ceiling effect (Gantz et al., 2002; Laszig et al., 2004; Wackym et al., 2007) as the scores achieved by the participants, using CI 1 only, were greater than 80%. Thus any benefits under bilateral conditions may not be apparent as the test parameters (e.g. presentation level, closed-set test) may have been too easy, resulting in the ceiling effect (Wackym et al., 2007).

4.2.1.4 Comparison between the performance with CI 1, CI 2 and BiCI

Table 4.2: Differences between the mean scores obtained for listening conditions B, E and G

Listening conditions being compared		Mean Scores being compared		Difference
B (CI 1)	**E** (CI 2)	24.6	19.8	4.8
B (CI 1)	**G** (bilateral)	24.6	24.8	0.2
E (CI 2)	**G** (bilateral)	19.8	24.8	5

From Table 4.2 it can be seen that performance was better under noisy conditions when either both cochlear implants (listening condition G) or only the first cochlear implant (listening condition B) was used as compared to when only the second cochlear implant (listening condition E) was used.

Participants performed slightly better (difference of 0.2; see Table 4.2) in the bilateral condition (listening condition G) as opposed to when only CI 1 (listening condition B) was used. This small improvement observed under listening condition G relative to listening condition B could be a display of a binaural benefit, specifically binaural summation. This result correlates with those reported by Senn et al. (2005) who also observed binaural benefit but did not obtain statistically significant differences. Similar findings, although significant in those studies, are reported in previous literature (Peters et al., 2007; Ricketts et al., 2006; Wackym et al., 2007) whereby binaural benefits were observed during speech perception testing. In the present study, however, the degree to which a significant binaural benefit exists could not adequately be observed due to the ceiling effect (Gantz et al., 2002; Laszig et al., 2004; Wackym et al., 2007) as all the participants obtained high scores under the unilateral condition (listening condition B).

A repeated measures ANOVA showed a significant difference ($p = 0.009$) amongst the participants' performances under listening conditions B, E and G. However, as the residuals were not normally distributed, the analysis was repeated non-parametrically (Munro, 2005). The Friedman non-parametric ANOVA confirmed the results of the repeated measures ANOVA as a significant difference ($p = 0.03$) was observed amongst the three listening conditions. However, the nature of this difference could not be established from the ANOVA results. The Bonferroni test was used for further analysis (Munro, 2005) and showed significant differences between the performances under listening conditions B and E ($p = 0.01$) and; E and G ($p = 0.02$). These results indicate that the participants obtained higher scores, when they were using CI 1 relative to CI 2 and when they were using both cochlear implants relative to CI 2. According to Senn et al. (2005), this difference in performance with CI 1 relative to CI 2 may be due to the difference in listening experience between the two ears. Similarly, the difference in performance between CI 2 and BiCI may be a reflection of the performance with CI 1 rather than a binaural summation. According to van Hoesel et al. (2005), some patients may perform equally well when using the first cochlear implant as when compared to performance with bilateral cochlear implants.

No significant difference was observed in performance under listening conditions B and G ($p = 1.00$). These findings are contrary to those reported by Peters et al. (2007) and Tyler, Dunn, Witt and Noble (2007), but are supported by those of Schafer and Thibodeau (2006) that no significant difference in performance was present when unilateral CI 1 conditions were compared to bilateral conditions (BiCI). A possible explanation for this finding may be that the participants had not yet learned to use the available cues during binaural stimulation. Litovsky et al. (2006) report that most pre-lingually deafened children, who receive cochlear implants sequentially, have never had binaural experience thus may have difficulty using the available cues and continue to predominantly use CI 1. However, the most likely explanation for the lack of observable binaural benefit in the present study is probably related to the ceiling effect. Since all the participants achieved high scores using CI 1 (unilateral condition), any improvement while using both cochlear implants would probably not be perceptible (Gantz et al., 2002; Laszig et al., 2004; Tyler et al., 2007; Wackym et al., 2007).

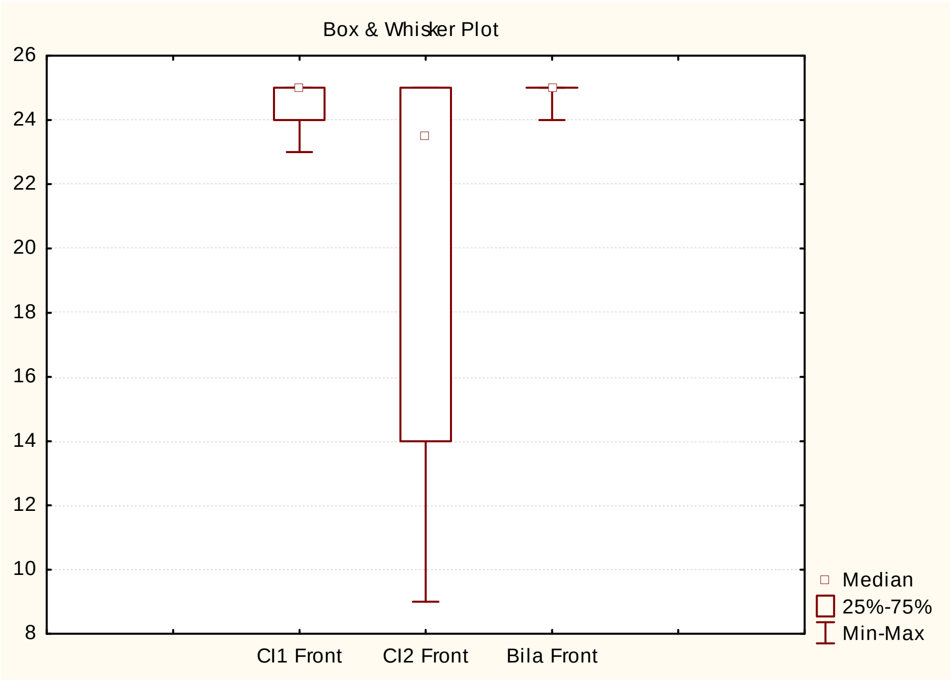


Figure 4.3: Comparison between listening conditions B (CI 1), E (CI 2) and G (BiCI)

Visual inspection of Figure 4.3 reveals that there were greater variations in raw scores, when the participants were using their second cochlear implant when compared to first implant use or bilateral use. Once again, these variations were possibly due to the fact that the participants had been using their second cochlear implants for a shorter time period than their first implants and that they were still learning to respond to auditory stimuli optimally (Wolfe et al., 2007). There was also variability in the time of implantation which meant the participants had various levels of proficiency with CI 2. This variability is expected when it is considered that speech perception abilities show significant improvement to about 5 years post-implantation (O’ Donoghue et al., 2000) and probably slow down or plateau after this period.

Although the difference in performance between CI 1 use and bilateral (BiCI) use was not significant, visual analyses of Figures 4.3 show that there was greater variation in the performance of participants when CI 1 was used when compared to the use of both cochlear implants. The greater consistency in performance under bilateral conditions may be an indication of binaural advantage as reported by other researchers (Peters et al., 2007; Ricketts et al., 2006; Wackym et al., 2007).

4.2.2 Competing noise ipsilateral to cochlear implant

An improvement in performance, while being tested under listening condition H relative to listening conditions C and F, was considered to be an indication of the head shadow effect. According to Schafer et al. (2007), the head shadow effect may be investigated by presenting the speech from a speaker at 0° azimuth and the noise from a speaker positioned on the same side as the test ear.

4.2.2.1 Performance with CI 1

The mean score for listening condition C, where the first cochlear implant was used, was 24.3 out of a maximum of 25. The raw scores obtained by the participants ranged from 22-25 (see Figure 4.1). Six participants (participants 2, 4, 5, 6, 8, and 10) obtained the maximum score of 25, while the other four participants (participants 1, 3, 7 and 9) obtained more than 80%.

4.2.2.2 Performance with CI 2

Testing under listening condition F, where the second cochlear implant was used, yielded a mean score of 19.6. The raw scores obtained by the participants ranged from 9-25 (see Figure 4.1). Four participants (participants 5, 6, 8 and 10) obtained the maximum of 25, while three participants (participants 3, 4 and 9) obtained results of 80% and above. Participants 1, 2 and 7 obtained the lowest scores of 12, 11 and 9 respectively. These 3 participants also had the longest time delay between receiving their first and second cochlear implants (i.e. 7 years 3 months; 6 years 6 months and 7 years 1 month respectively). Research by Gordon et al. (2007) suggests that children who receive a second cochlear implant, with long delays between the two implants, may not show significant improvements or they may improve at a slower rate than children who have had short delays between their two implants.

4.2.2.3 Performance with BiCI

The raw scores obtained under listening condition H, where both cochlear implants were used, ranged from 24-25. The mean score for this listening condition was 24.9 (see Figure 4.1). Only participant 3, with a raw score of 24, did not obtain the maximum score of 25. A possible reason for these high scores was that the test was not challenging enough and therefore, a ceiling effect was observed (Firszt et al., 2004).

4.2.2.4 Comparison of performance with CI 1, CI 2 and BiCI

Table 4.3: Differences between the mean scores obtained for listening conditions C, F and H

Listening conditions being compared		Mean Scores being compared		Difference
C (CI 1)	**F** (CI 2)	24.3	19.6	4.7
C (CI 1)	**H** (BiCI)	24.3	24.9	0.6
F (CI 2)	**H** (BiCI)	19.6	24.9	5.3

From Table 4.3 it can be seen that performance was better under noisy conditions when either both cochlear implants (listening condition H) or only the first cochlear implant (listening condition C) was being used compared to when only the second cochlear implant (listening condition F) was used. A few possible reasons for better performance with CI 1 are: that the participants used CI 1 for a greater length of time compared to CI 2 use; that the ear in which CI 1 was implanted experienced a shorter period of auditory deprivation and; that CI 1 was implanted in the better ear (Scherf et al., 2007). Furthermore, participants performed slightly better (difference of 0.6; see Table 4.3) in the bilateral condition (listening condition H) as opposed to when only CI 1 (listening condition C) was used. Although, not significant, the improvement in performance may be an indication of a head shadow effect. This finding supports previous research (Galvin et al., 2007; Kühn-Inacker et al., 2004; Müller et al., 2002; Murphy & O' Donoghue, 2007; Peters et al., 2004; 2007; Schleich et al., 2004; van Hoesel et al., 2002) that reported on binaural advantages under noisy conditions.

A repeated measures ANOVA showed a significant difference ($p = 0.01$) amongst the subjects' performances under listening conditions C, F and H. However, as the residuals were not normally distributed, the analysis was repeated non-parametrically. The Friedman non-parametric ANOVA confirmed the results of the repeated measures ANOVA as a significant difference (p = 0.01) was observed amongst the three listening conditions. Further analysis using the Bonferroni test was used to compare the performances under the specific listening conditions (Munro, 2005). A significant difference was obtained between the performances under listening conditions C and F (p = 0.03); and F and H (p = 0.01).

Findings by other researchers (Galvin et al., 2007; Peters et al., 2004; 2007; Senn et al., 2005) support the finding that participants performed better with their first cochlear implant relative to their second cochlear implant. However, Peters et al. (2004) related this difference in performance specifically to children within the age group 8 to 13 years. Within the present study, 7 out of the 10 participants were within this age range. A possible reason for the discrepancy in performance with CI 1 relative to CI 2 is that the participants' reliance on CI 1 due to prolonged exposure to unilateral stimulation only, had negatively impacted on their ability to attend to CI 2 (Peters et al., 2007). Additional reasons for poorer performance with CI 2 may include limited auditory acclimatization, as the participants had been using CI 2 for a shorter time relative to CI 1 and had therefore not yet fully adapted to CI 2, and auditory deprivation, because the second implanted ear had been deprived of auditory stimulation for a longer period and therefore performed poorer in response to auditory stimulation (Senn et al., 2005).

No significant difference was observed in performance under listening conditions C and H (p = 1.00). This result supports those obtained by Scherf et al. (2007), who did not find a statistically significant difference between unilateral and bilateral performance in noise. These researchers specifically reported this finding for children who received the second implant after the age of 6 years. Within the present study, 6 out of the 10 participants were implanted with CI 2 after they were 6 years of age. According to Sharma, Dorman and Kral (2005), a critical period for central auditory development exists and if a cochlear implant is implanted after this age, performance may be compromised. If this view is considered, it may be possible that the benefit from a second cochlear implant, if it is implanted after the critical period, is limited.

Schafer and Thibodeau (2006) reported similar findings, where no significant difference was found between speech-in–noise thresholds for the unilateral condition (CI 1), relative to the bilateral (BiCI) condition. However these researchers, as well as, Galvin et al. (2007) noted that certain individual participant's demonstrated improvement with binaural stimulation relative to monaural stimulation. Other researchers (Kühn-Inacker et al., 2004; Müller et al., 2002) have found results contrary to these findings and have reported on significant binaural benefits. A possible reason for the differences in the present study and that of Kühn-Inacker et al. (2004) was that all the participants in that study used the MED-EL Combi 40 or 40+ cochlear implants, while all the children in the present study were implanted with the Nucleus 24 cochlear implants. The MED-EL cochlear implant systems implemented the Continuous Interleaved Sampling (CIS) speech processing strategy while the Nucleus systems applied the ACE coding strategy (Clark, 2003). Furthermore, the target signal was presented from two speakers at 135° and 115° azimuth, while the competing noise was presented at 45° and 225° azimuth. The Kühn-Inacker et al. study (2004) also involved a greater number of participants and fewer conditions, which is likely to have contributed to the findings being significant.

Lastly, it is possible that the lack of a significant difference may be due to a ceiling effect. As the participants were already obtaining high scores under unilateral conditions, it may not be possible to observe any bilateral benefit, if any were present (Gantz et al., 2002; Laszig et al., 2004; Wackym et al., 2007).

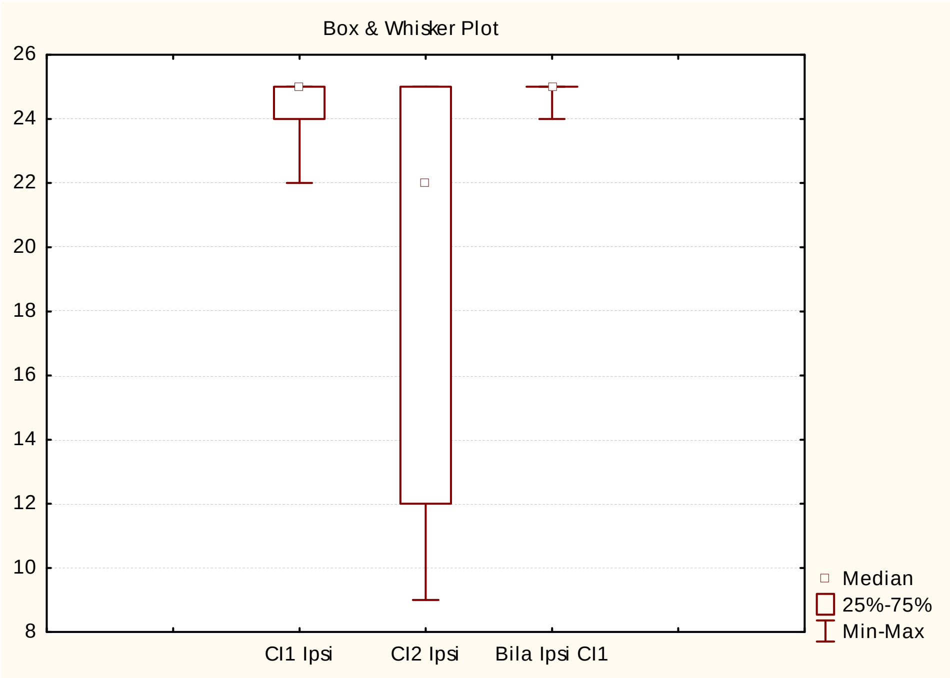


Figure 4.4: Comparison between listening conditions C (CI 1), F (CI 2) and H (BiCI)

Visual inspection of Figure 4.4 reveals that there were greater variations in raw scores, when the participants were using their second cochlear implant instead of their first cochlear implant or both cochlear implants. It is expected that more consistent results would be obtained with the first cochlear implant, as all the participants had been using CI 1 for a minimum of 4 years, thus their performance with this implant had reached optimal levels. According to Dowell et al. (2002), the most noticeable improvements occur within the first 4 years post implantation, after which, it is assumed that performance will be stable. Furthermore, the side with CI 1 experienced less auditory deprivation and had a longer time to learn to process the auditory signal adequately (Senn et al., 2005; Wolfe et al., 2007). In contrast to the duration of use of CI 1, all the participants had been using their second cochlear implants for less than 4 years, thus all of their performances had not yet reached optimal levels and greater differences between participants were observed. It should also be noted that there were differences between subjects with regards to the length of time that they had been using the second cochlear implant.

Although the difference in performance between CI 1 use and bilateral use was not significant, visual analysis of Figure 4.4 shows there was greater variation in the performance of participants when CI 1 was used when compared to the use of both cochlear implants. This may be evidence of binaural benefit, specifically the head shadow effect (Galvin et al., 2007).

4.3 SPEECH RECOGNITION AND DURATION OF COCHLEAR IMPLANT USE

The fourth sub-aim was to determine whether a correlation existed between the participants' speech recognition abilities and the duration of cochlear implant usage. This was achieved by analysing the results obtained on the CRISP test (see Figure 4.1) relative to the length of time that the participants were using their respective cochlear implants (see Table 3.1; p. 26). Regression analyses were used since the response variables (which were ordinal in nature) were not normally distributed (Terre Blanche & Kelly, 1999).

4.3.1 Speech recognition and LOU of CI 1

The length of use (LOU) for the first cochlear implant ranged from 4 years 0 months to 8 years 11 months (see Table 3.1; p. 26), with an average LOU of 6 years 5 months.

A regression analysis showed a significant Spearman correlation (p = 0.04) between the LOU for CI 1 and the participants' performances, when the noise was presented from the front (listening condition B; see Figure 4.6). This finding indicates that for this particular group of participants, improvement in performance was related to the length of time that they had been using their first cochlear implant, when both the target sound and the competing noise was located at the front. As all the children had been using their first cochlear implants for a long time, it was expected that their performance would improve. This finding is supported by those reported by Geers, Brenner and Davidson (2003), who found that children displayed substantial benefits in speech perceptual abilities 4 to 7 years post implantation, thus improvement in performance would still be evident prior to this period.

No significant correlations were observed between the subjects' performances and the length of use of the first cochlear implant under the following listening conditions:

- When the first cochlear implant was used and the noise was absent; $p = 0.12$ (listening condition A; see Figure 4.5)
- When the first cochlear implant was used and the noise was presented ipsilateral to CI 1; $p = 0.43$ (listening condition C; see Figure 4.7)
- When both cochlear implants were used and the noise was presented from the front; $p = 0.72$ (listening condition G; see Figure 4.8)
- When both cochlear implants were activated and the noise was presented ipsilateral to CI1; $p = 0.63$ (listening condition H; see Figure 4.9)

The lack of correlation found may be due to a ceiling effect, as all the participants were already displaying good performance (80% and more) under all the conditions. The ceiling effect has also been used to explain the lack of improvement in similar studies as reported by Gantz et al. (2002) and Laszig et al. (2004). It was, therefore, not possible to observe the relationship between LOU of CI 1 and time, if any existed, as the scores obtained were at or close to the maximum.

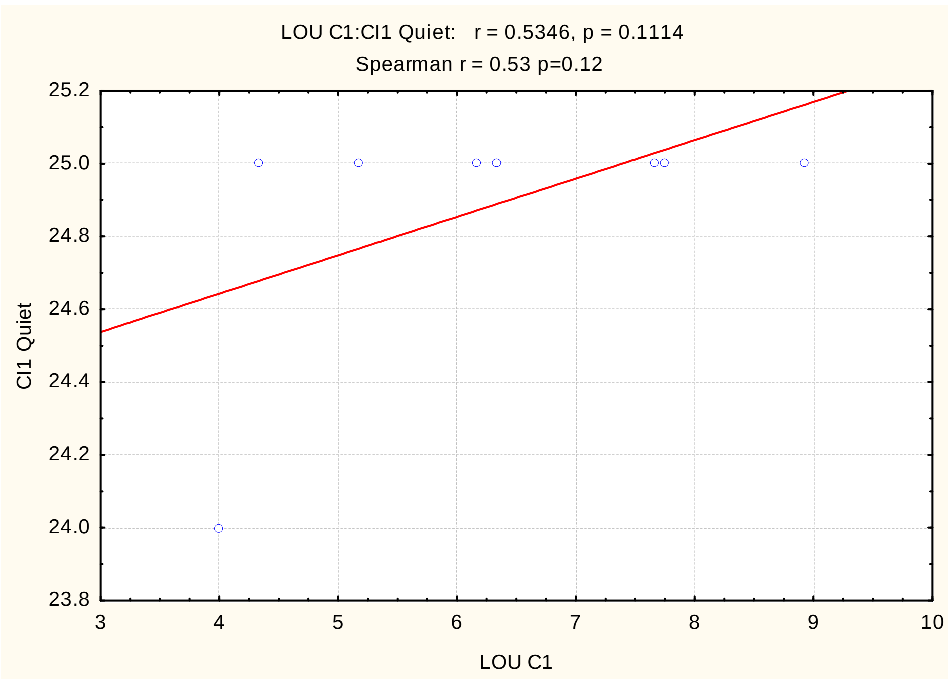


Figure 4.5: Correlation between listening condition A (CI 1) and LOU of CI 1

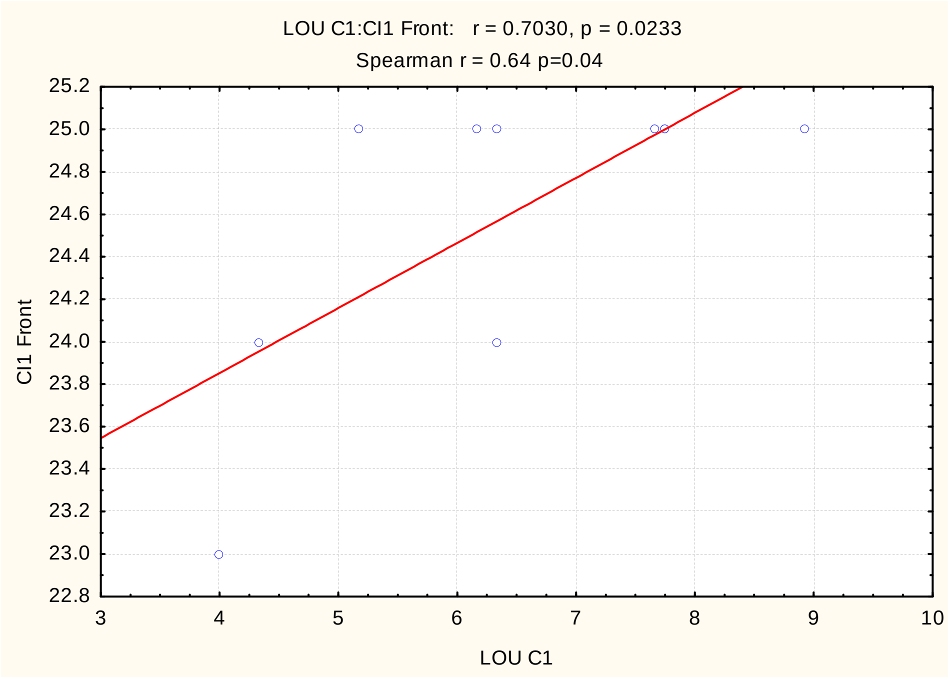


Figure 4.6: Correlation between listening condition B (CI 1) and LOU of CI 1

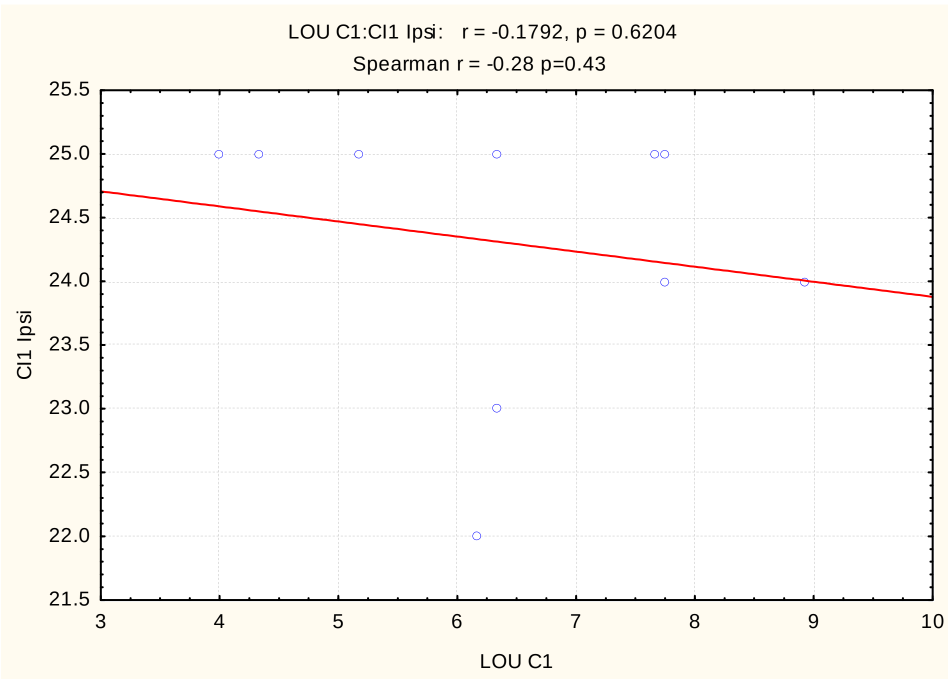


Figure 4.7: Correlation between listening condition C (CI 1) and LOU of CI 1

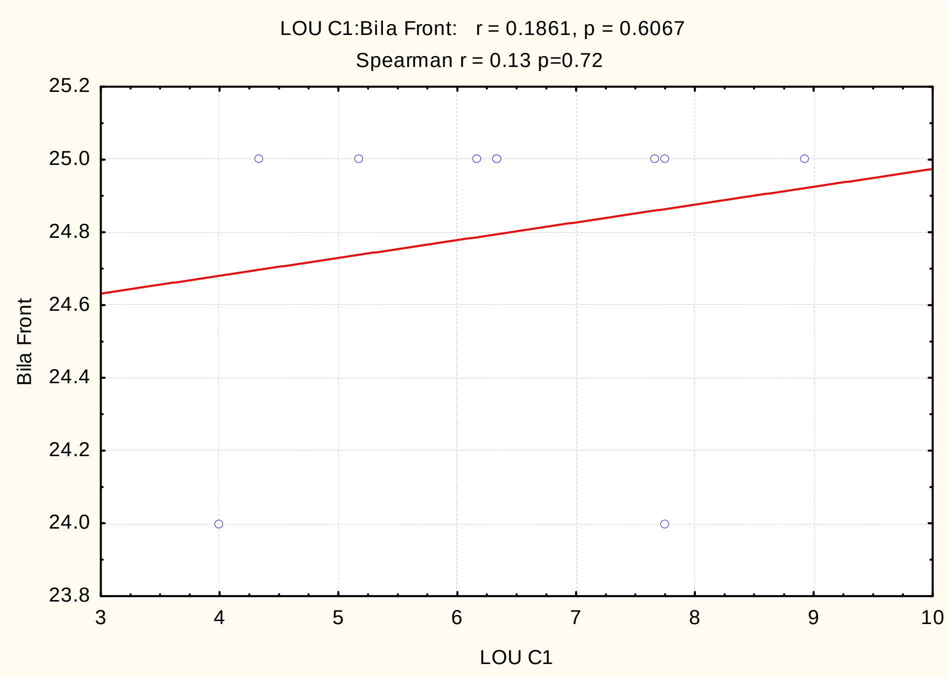


Figure 4.8: Correlation between listening condition G (BiCI) and LOU of CI 1

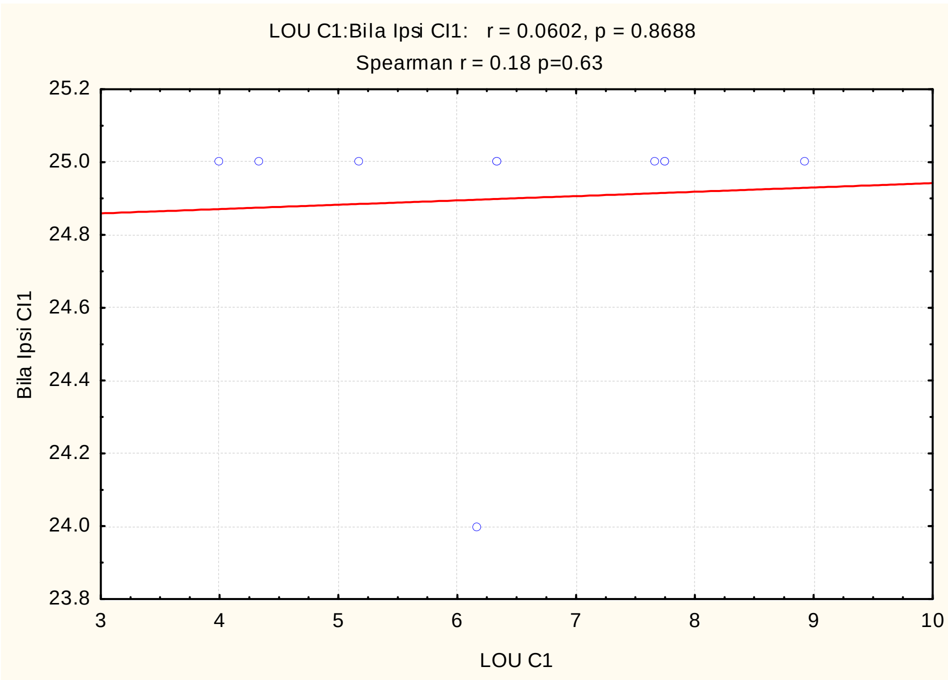


Figure 4.9: Correlation between listening condition H (BiCI) and LOU of CI 1

4.3.2 Speech recognition and LOU of CI 2

The LOU for the second cochlear implant ranged from 7 months to 3 years five months (see Table 3.1; p. 26). The average LOU for the second cochlear implant was 2 years 1 month.

A regression analysis showed significant Spearman correlations between the participants' performances and the length of use of the second cochlear implant under the following listening conditions:

- When the second cochlear implant was activated and the noise was absent; $p = 0.05$ (listening condition D; see Figure 4.10)
- When the second cochlear implant was activated and the noise was presented from the front; $p = 0.00$ (listening condition E; see Figure 4.11)
- When the second cochlear implant was activated and the noise was presented ipsilateral to CI 2; $p = 0.04$ (listening condition F; see Figure 4.12)

These findings indicate that for this particular group of participants, performance improved with increasing length of time that they had been using their second cochlear implant. According to Gfeller et al. (2007), a strong correlation exists between the duration of implant use and speech perception skills, thus it can be used to predict perceptual outcomes. Although Geers et al. (2003), reported on children, who only had unilateral implants, it is assumed that the trend (namely, significant benefits in speech perception 4 to 7 years post implantation) identified in their research may be applicable to the use of CI 2. As all the children had been using their second cochlear implants for less than 4 years, it was expected that improvement would still be noted during this period.

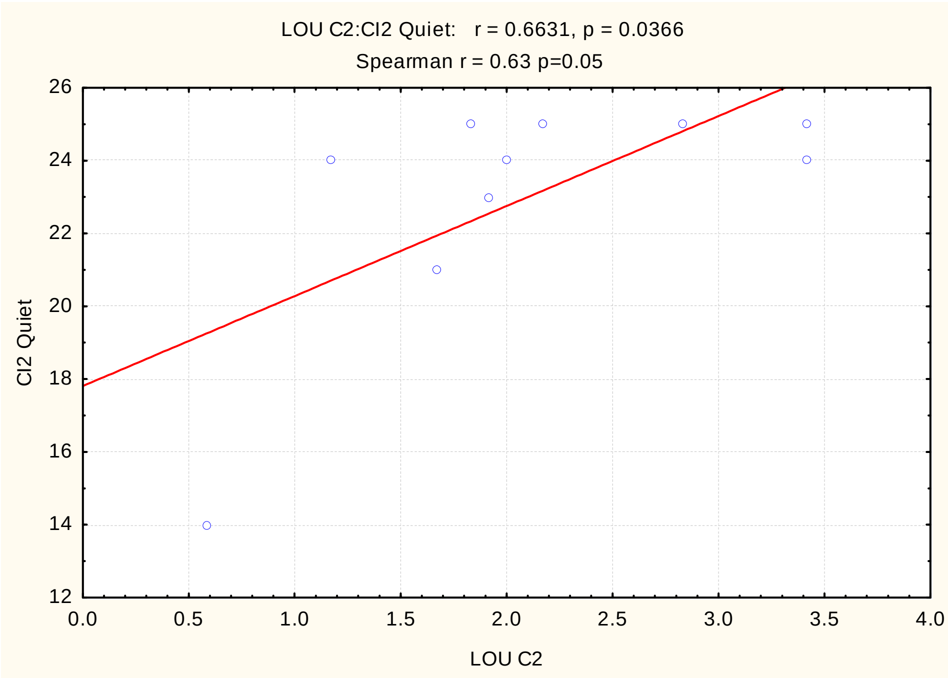


Figure 4.10: Correlation between listening condition D (CI 2) and LOU of CI 2

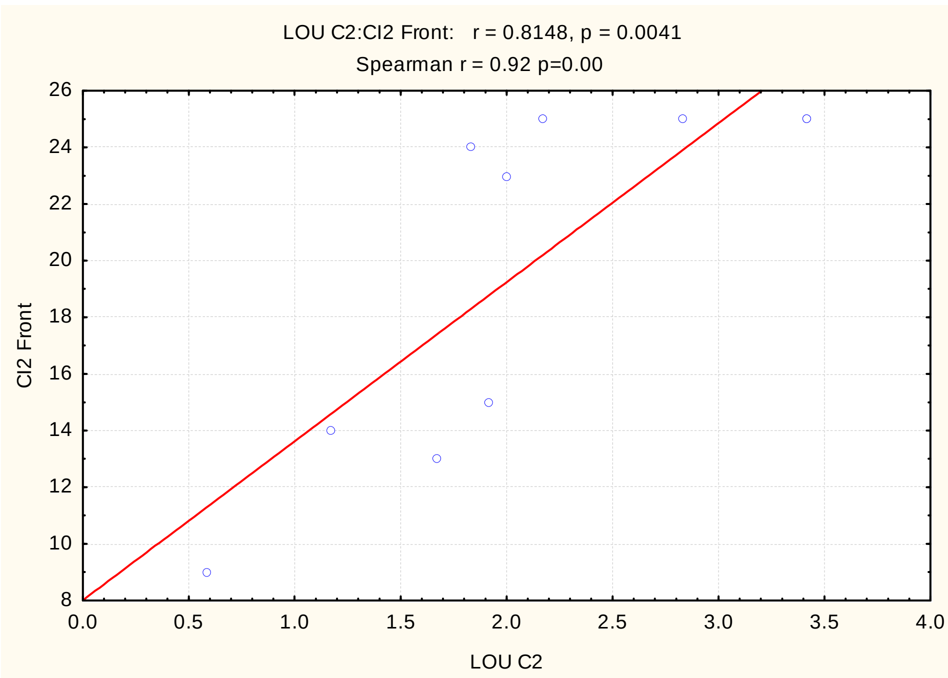


Figure 4.11: Correlation between listening condition E (CI 2) and LOU of CI 2

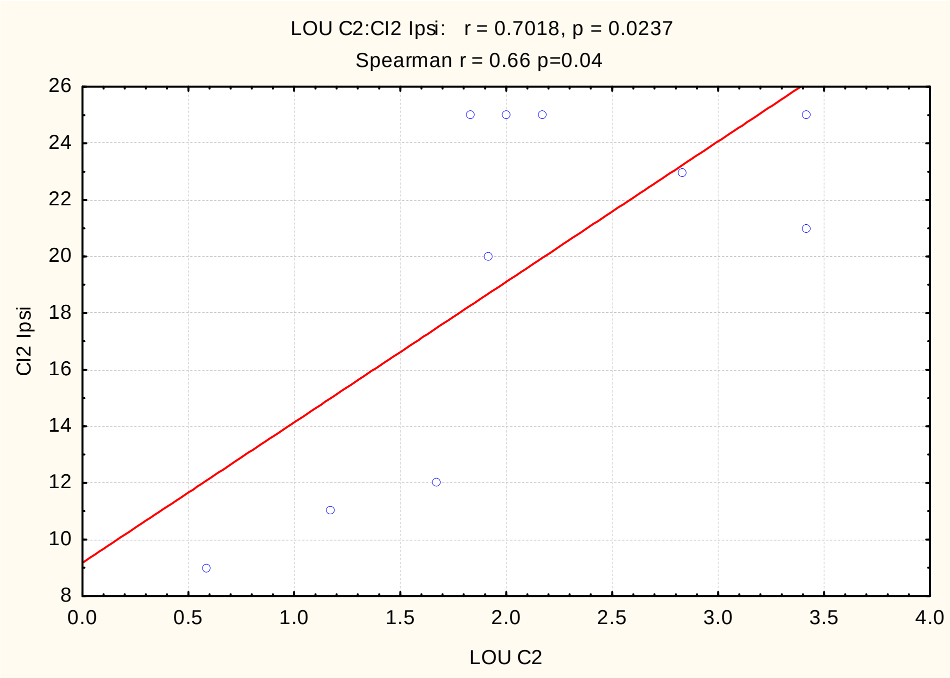
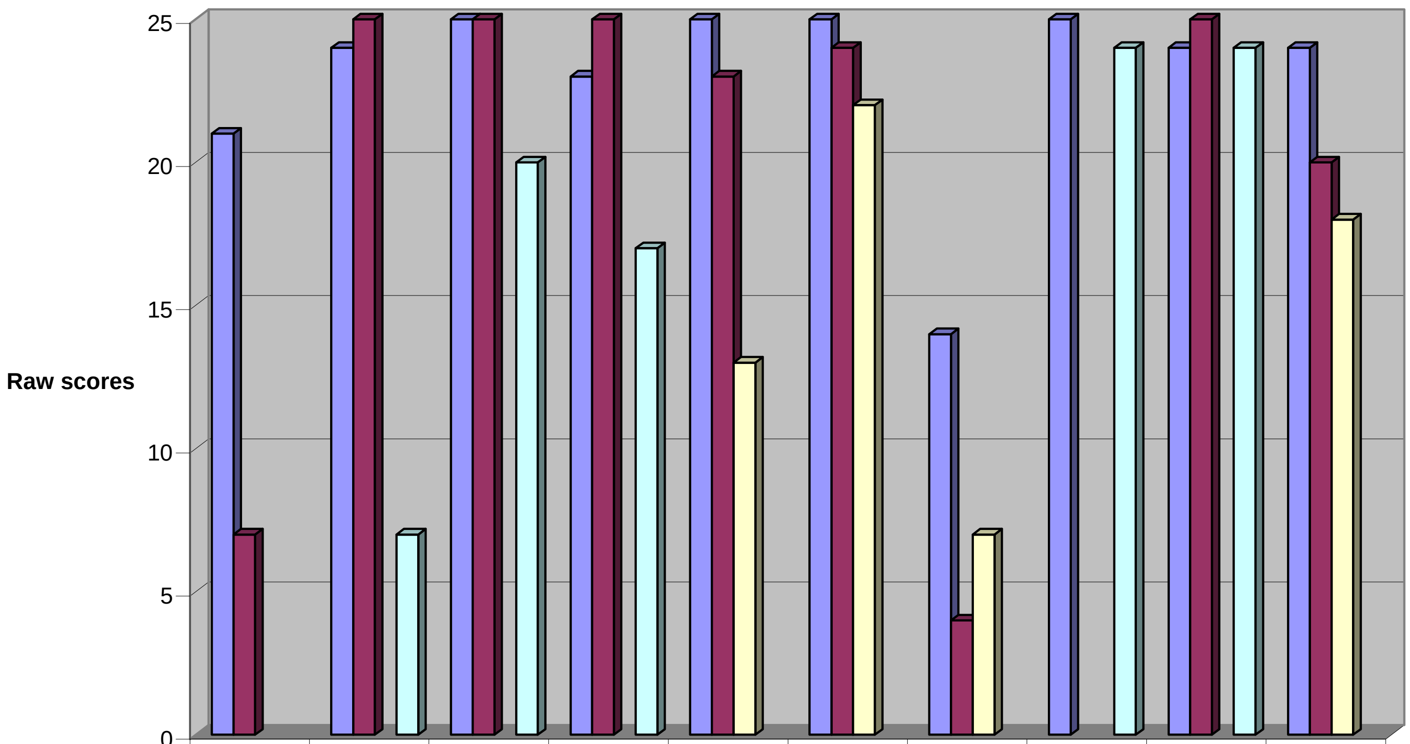


Figure 4.12: Correlation between listening condition F (CI 2) and LOU of CI 2



	1	2	3	4	5	6	7	8	9	10
CRISP	21	24	25	23	25	25	14	25	24	24
BKB	7	25	25	25	23	24	4		25	20
PBK Words					13	22	7			18
ODPI		7	20	17				24	24	

Participants

Figure 4.13: Results of speech perception tests (CI 2 in quiet)

4.4 COMPARISON OF SPEECH PERCEPTION RESULTS USING CI 2 IN QUIET

The fifth sub-aim was to compare the raw scores obtained on the CRISP to those obtained on other speech perception tests. It was thought that the comparison was necessary to determine whether the raw scores obtained on the CRISP test gave a good indication of the speech perception abilities of the participants as reflected by other speech perception tests. However, it is noted that the comparison of results between these tests may not be appropriate as the stimuli contained in each test is not necessarily equivalent (Dunn et al., 2005).

Figure 4.13 reflects the raw scores obtained for the CRISP, BKB, PBK word lists and ODPI tests. The CRISP results were obtained during testing, while the other results were obtained during the review of the participants' records. All the participants were tested using the CRISP test. However, on review not all the participants had previously been tested using the same test. Thus the results of the CRISP were compared to the particular test results that appeared in the participants' records. Due to this, the number of participants (n) varied as a function of the tests being compared. Listening condition D (CI 2 in quiet) was selected as results for all the subjects were available for this condition, even though different speech perception tests had been used.

4.4.1 Comparison between CRISP and BKB

This comparison was only performed for 9 participants for whom the scores of the BKB were available. The raw scores obtained for the CRISP test ranged from 14-25, with a mean score of 22.8. The raw scores obtained for the BKB test ranged from 4-25, out of a maximum of 25 (see Figure 4.13). The mean score obtained was 19.8. The average difference between the mean scores for the CRISP and BKB test was 3, with better raw scores being obtained on the CRISP test. A repeated measures Analysis of Variance (ANOVA) showed that this difference was not significant ($p = 0.140$). Since the residuals were not normally distributed, the analysis was repeated using a non-parametric test. The Wilcoxon Matched Pairs Test confirmed the parametric analysis as the difference of 3 was shown to not be significant ($p = 0.183$). It should be noted that the findings obtained were probably influenced by the size of the sample as only 9 scores were being compared. Koch (1999; in McConkey Robbins, 2000b) identifies a hierarchy of speech perception tests. According to this, sentences are just above closed-set words. Thus the possibility exists that performance on these two tests do not differ significantly.

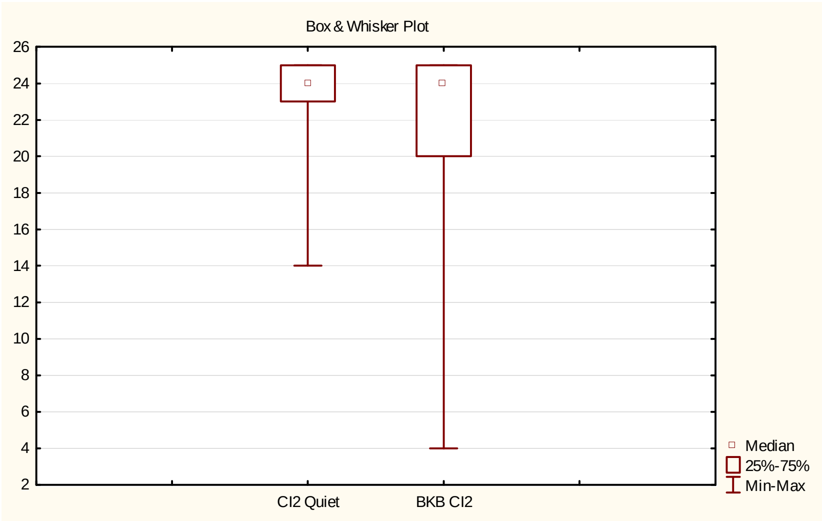


Figure 4.14: Comparison between CRISP and BKB

Although the difference in performance on the CRISP and BKB tests were found not to be significant, visual inspection of Figure 4.14 reveals that there were greater variations in raw scores, when the participants were tested using the BKB, than the CRISP test. The raw scores on the CRISP test ranged from 14-25, whereas the raw score range on the BKB test extended from 4-25 (see Figure 4.13). Participant 7 had the lowest scores for both CRISP and BKB tests (14 and 4 respectively). These low scores were probably related to the length of use of CI 2, as both tests were performed prior to 12 months of CI 2 use (Peters et al., 2007). However, participant 1 obtained a raw score of 21 on the CRISP, but scored particularly poorly (7 out of a maximum of 25) on the BKB test. This discrepancy in results is expected as the BKB test was performed 11 months before the CRISP. At that stage, participant 1 had only been using CI 2 for a period of 9 months. This finding is supported be Gfeller et al. (2007), as well as previous results described in the present study, which indicate a positive correlation between performance and length of use of CI 2.

4.4.2 Comparison between CRISP and PBK Words

This comparison was only performed for 4 subjects for whom the scores for the PBK were available. The raw scores obtained for the CRISP test ranged from 14-25, with a mean score of 22. The raw scores obtained for the PBK word list ranged from 7-22, out of a maximum of 25. The average raw score obtained was 15 (see Figure 4.13). The average difference between the mean scores for the CRISP and PBK word list was 7, with better raw scores being obtained on the CRISP test. A repeated measures Analysis of Variance (ANOVA) showed that this difference was significant (p = 0.033). Since the residuals were also normally distributed the analysis was not repeated using a non-parametric test. These findings therefore indicate that participants performed better when tested on the CRISP than on the PBK word list. The better performance on the CRISP test may be related to the difference in complexities of the two tests. The CRISP test is a closed-set test, which requires the ability to recognise spondee words. Furthermore, participants may be familiarised with the words (Litovsky, 2003). The PBK word lists consist of monosyllabic words, which are expected to be within the child's vocabulary. It is an open-set test and the words must not be practised with the child prior to testing (Haskins, 1964; in Clark, 2003). According to the hierarchy of listening tasks outlined by McConkey Robbins (2000b), closed set tasks are easier than open set tasks. Therefore better performance can be expected on these. The finding that the CRISP is an easier test is expected if cognizance is taken of the hierarchy of listening tasks.

The identification of spondee words is considered to be less difficult than the identification of monosyllabic words as it has increased external redundancy (Stach, 1998). According to the speech perception categories of the Central Institute for the Deaf (Geers, 1994; in Kirk, 2000), the identification of spondee words falls within category 3, while the recognition of monosyllables falls within categories 4 and 5. Thus the identification of monosyllables is higher up on the speech perception hierarchy (Lee & van Hasselt, 2005) making the PBK word lists a more difficult task.

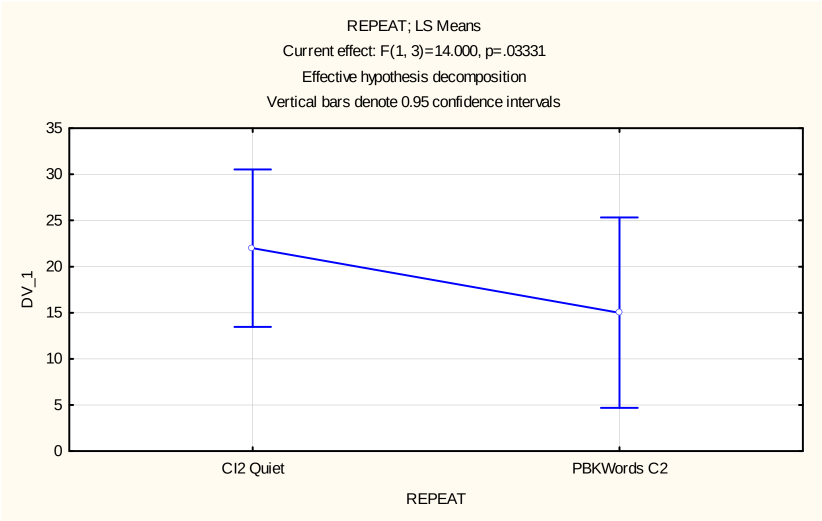


Figure 4.15: Comparison between CRISP and PBK Words

Visual inspection of Figure 4.15 reveals that there were greater variations in raw scores, when the participants were tested using the PBK word list, rather than the CRISP test. The raw scores on the PBK word list ranged from 7-22; whereas the raw scores on the CRISP test ranged from 14-25 (see Figure 4.13). Participant 7 had the lowest scores for both tests (14 and 7 respectively). This result was probably due to the fact that both tests were done prior to 12 months of CI 2 use (Peters et al., 2007). However, participants 5 and 10 obtained raw scores above 80% on the CRISP, but obtained scores of less than 80 % (52% and 72% respectively) on the PBK word lists. The PBK had been performed 2 months (for participant 5) and 3 months (for participant 10) prior to the CRISP. At the time that the PBK was performed, both participants had been using CI 2 for longer than 12 months. A possible reason for the difference in performance may be that the open-set task was too difficult for these two participants (Koch, 1999; in McConkey Robbins, 2000b) when compared to the closed-set task. Alternatively the CRISP was too easy for the majority of the participants and the results reflect a ceiling effect (Wackym et al., 2007). A final possibility is that the better performance on the CRISP was as a result of longer cochlear implant use (Gfeller et al., 2007).

4.4.3 Comparison between CRISP and ODPI

This comparison was only performed for 5 subjects for whom the scores for the ODPI were available. The raw scores obtained for the CRISP test ranged from 21-25, out of a maximum of 25. The mean score obtained was 24.2. The raw scores obtained for the ODPI test ranged from 7-24, out of a maximum of 25, with a mean score of 18.4 (see Figure 4.13). The average difference between the mean scores for the CRISP and ODPI test was 5.8, with better raw scores being obtained on the CRISP test. A repeated measures Analysis of Variance (ANOVA) showed that this difference was not significant (p = 0.127; see Figure 4.15). Since the residuals were fairly normally distributed and since the sample size was small, the analysis was repeated using a non-parametric test. The Wilcoxon Matched Pairs Test confirmed the parametric analysis as the difference of 5.8 was shown to not be significant (p = 0.068). These findings indicate that performance on the CRISP was not better than performance on the ODPI. Similar results on the two tests were expected as both tests are closed-set tests. In addition, as one test consists of monosyllabic words and the other test of spondee words, the absence of a significant difference might also be due to the small size of the sample.

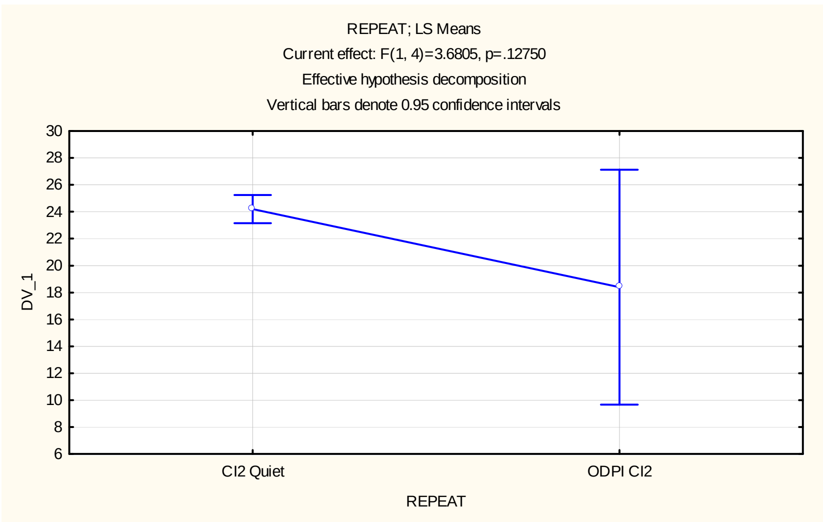


Figure 4.16: Comparison between CRISP and ODPI

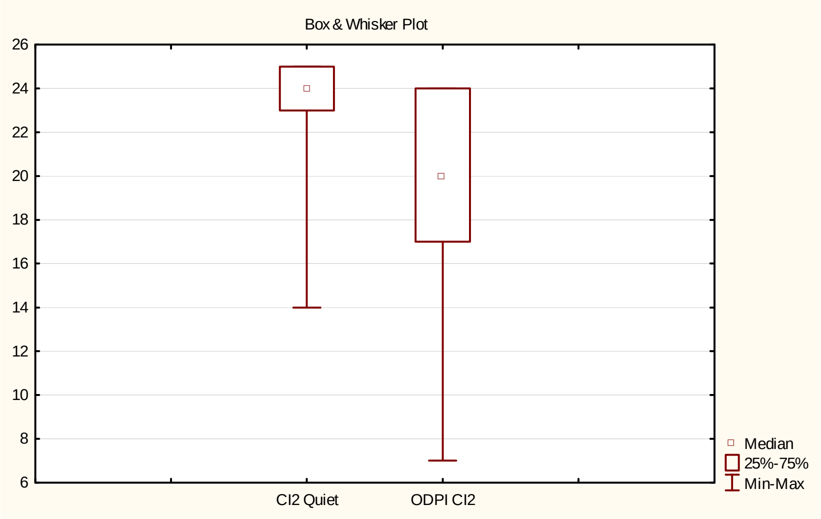


Figure 4.17: Comparison between CRISP and ODPI

Although the difference between performance on the CRISP and ODPI was not significant, visual inspection of Figures 4.16 and 4.17 were done. As can be seen from the figures, there were greater variations in raw scores when the participants were tested using the ODPI test than when they were tested on the CRISP test. The raw scores on the ODPI word list ranged from 7-24; whereas the raw score range on the CRISP test was 23-25 (see Figure 4.13). Participant 2 had the lowest score for the ODPI test, 7 out of 25, but performed well on the CRISP. A possible reason for this is that the ODPI was performed prior to 12 months of cochlear implant use, while the CRISP was performed after 12 months, even though the time between the two tests was only 4 months. Peters et al. (2007) indicate that substantial growth in speech perception abilities take place during the first twelve months of cochlear implant use. Only one other participant, participant 4 obtained less than 80% (namely, 68%) on the ODPI test. All the participants, however, obtained more than 80% on the CRISP. The ODPI consists of monosyllables while the CRISP contains spondees. According to the speech perception categories of the Central Institute for the Deaf (Geers, 1994; in Kirk, 2000), the identification of spondee words falls within category 3, while the recognition of monosyllables falls within category 4 and 5. Thus the identification of monosyllables is higher up on the speech perception hierarchy and is considered to be a more difficult task (Lee & van Hasselt, 2005). The participants who performed less than optimally on the ODPI may, therefore, have had speech perception skills which were within category 3, at the time of testing.

4.5 SUBJECTIVE OBSERVATIONS

Finally, although the study used a relatively small number of subjects and focussed only on measures of speech recognition, it was considered important to comment on the observations made during the data collection process.

During conversations with the participants, 9 out of the 10 participants indicated that they were benefiting from the use of CI 2. Similarly in research by Galvin et al. (2007), most of the participants were positive about the use of two cochlear implants. The only exception in the present study was participant 1, who claimed that he “could hear nothing” with his second cochlear implant. A possible explanation for the participant’s assertion that CI 2 was of no benefit is that this participant had the greatest delay between acquiring CI 1 and CI 2 (7 years 3 months) and he was also the oldest (13 years 8 months) when he was implanted with CI 2. According to research (Peters et al., 2007), older children typically use their first cochlear implants for a lengthy period of time before receiving the second implant. During this period, they become very reliant and aware of that implant. This extended period of unilateral use may cause reluctance on the part of the child to actively pay attention to and use the second implant. This lack of attention to the second implant may be perceived as a lack of benefit.

During the testing procedure itself, it was noted that all the participants appeared comfortable and confident in the listening conditions involving CI 1 and BiCI, more so in the BiCI conditions. However, as soon as they were told to switch CI 1 off, they appeared anxious. Although not measured, subjectively it was evident that they took longer to respond and seemed unsure of their responses in listening conditions involving CI 2 only. It is expected that the participants would be more comfortable under CI 1 conditions, as they had all been using this cochlear implant for a number of years prior to testing and had acclimatized to auditory stimulation (Senn et al., 2005). The findings in the present study, related to BiCI, correlate with previous literature reporting that bilateral cochlear implants are associated with ease of listening (Kühn-Inacker et al., 2004; Litovsky et al., 2006; Wackym et al., 2007). Furthermore, these observations correlate with those of Bohnert et al. (2006), who reported that parents and children indicated that bilateral cochlear implants were associated with increased self-assurance, better awareness and response orientation to acoustical stimuli and improved concentration.

CHAPTER 5: GENERAL DISCUSSION AND CONCLUSIONS

5.1 GENERAL DISCUSSION

Previous research has documented many benefits of bilateral cochlear implants. The present study was conducted to investigate speech recognition of children fitted with bilateral cochlear implants under binaural (BiCI) and monaural (CI 1 or CI 2 only) listening conditions, in quiet and in noise. In order to achieve this, the following specific aims were formulated:

1. To investigate the speech recognition of children utilizing one (unilateral) cochlear implant in quiet
2. To investigate the speech recognition of children utilizing one (unilateral) cochlear implant in the presence of competing noise
3. To investigate the speech recognition of children utilizing two (bilateral) cochlear implants in the presence of competing noise
4. To determine whether a correlation existed between speech perception abilities and duration of cochlear implant use
5. To compare performance on the CRISP, when using CI 2 in quiet, to performance on other speech perception measures

In the present study, the binaural benefit (specifically binaural summation and head shadow effect) observed in noise was not considered to be statistically significant when compared to scores obtained with the first cochlear implant. Despite this finding, subjective observations of the participants indicated increased self assurance, ease of listening and quicker responses with bilateral implants. These observations may be an indication of binaural benefit as described in the literature (Bohnert et al., 2006; Kühn-Inacker et al., 2004; Litovsky et al., 2006; Wackym et al., 2007). It is possible that the participants did not show improvement, in the bilateral condition, because they were already obtaining high scores in the unilateral condition while using the first cochlear implant. These results may, therefore, be related to a ceiling effect, rather than a lack of binaural advantage (Gantz et al., 2002; Laszig et al., 2004; Wackym et al., 2007).

The results of the present study suggest that cochlear implant users perform poorer, in quiet and in noise, while using their second cochlear implants, when compared to performance with bilateral implants and the first cochlear implant. Similar findings have been reported by various authors (Buss et al., 2008; Laszig et al., 2004; Peters et al., 2007; Scherf et al., 2007). Possible reasons for the discrepancy in performance are: that the participants had more experience with the first cochlear implant as they were using it for a longer period relative to the second implant and; that the second ear had a longer period of auditory deprivation and, therefore, did not respond as well to auditory stimulation (Senn et al., 2005).

According to the present findings, a significant correlation existed between performance, in quiet and in noise, and the length of time the second cochlear implant had been used. Similar findings have been reported by Gfeller et al. (2007). A significant correlation also existed for performance in noise (located at the front) and the duration of use of the first cochlear implant. As literature suggests that benefits in speech perception can occur until 4 to 7 years post implantation (Geers et al., 2003), it is possible that the strong correlation was due to the fact that the participants were still developing their speech perception skills and thus improvement will be noted over time.

The findings suggest that performance on the CRISP test was not significantly different to performance on the BKB and ODPI, but greater variation was noted in performance, for these two tests. It should be noted that the absence of statistically significant findings may have resulted from the small sample size. According to the results, statistically higher scores were obtained on the CRISP relative to the PBK word lists. When one considers the existing literature, this finding was expected, as the PBK is an open-set test consisting of monosyllabic words, while the CRISP is a closed-set test consisting of spondee words. According to literature, closed-set tasks are considered to be easier than open-set tasks (McConkey Robbins, 2000b), while monosyllables are considered to be more difficult stimuli than spondee words (Lee & van Hasselt, 2005). It should be noted that comparison between results obtained on different tests may not always be appropriate as the complexity of the tests are not equal (Dunn et al., 2005).

In general, greater variability in the performance of the participants could be observed when the second cochlear implant was used, relative to the use of the first cochlear implant or both implants. Possible reasons for this could be that the duration of use for the second cochlear implant was less than that for the first implant. In addition, there were variations in the length of use for both implants, while performance with the first cochlear implant had stabilized as the length of use exceeded 4 to 5 years (Dowell et al., 2002; O' Donoghue et al., 2000). It is possible that the second ear was still in the process of acclimatizing to auditory stimulation (Senn et al., 2005).

5.2 CONCLUSION

In the present study, binaural benefit for speech recognition was not statistically significant either in quiet or in noise. It is possible that this lack of significance was due to a ceiling effect. Binaural benefit, if present, could not be observed as the scores obtained in the unilateral conditions were already close to the ceiling. Further improvements under bilateral conditions were probably limited by the testing procedure, rather than the absence of bilateral advantage. It is further noted that the CRISP, which is a closed-set test consisting of spondee words, appears to have been too easy for the participants.

As with other studies, a positive correlation was established between length of use of the second cochlear implant and speech perception performance. This information may be useful to patients, clinicians and parents, as anxiety may be experienced initially after the implantation when speech perception abilities are still limited.

A strong recommendation based on the results of the present study is that testing paradigms, in particular for bilateral cochlear implant users, need to be reassessed so that the testing conditions are more representative of the complex auditory environments in which we function. These adaptations to testing protocol could include reducing the presentation level to 50 or 60 dB SPL, as well as including multiple noise sources and using more complex speech stimuli.

If we are to recommend bilateral implants, we need documented outcomes which justify both the costs and risks involved in this choice of treatment for hearing impaired individuals.

CHAPTER 6: CRITIQUE AND IMPLICATIONS

6.1 CRITIQUE

"Professionals who cannot evaluate research data and theories also cannot make effective use of information" (Hegde, 2003, p. 17).

Caution should be exercised when drawing conclusions of the results and generalization of these findings to all bilaterally implanted children may not be possible. Several factors including: the age at testing, the age at implantation, the duration of CI 1 and CI 2 use, the time delay between the two cochlear implants and the hearing levels, may have affected the results. However, definitive statements with regards to the impact of these factors cannot be made due to the limited sample pool and heterogeneity of the population (Murphy & O' Donoghue, 2007). An attempt was made to attain a reasonable degree of conformity by specifying inclusion and exclusion criteria. Furthermore, all the participants used similar processors and the same coding strategies. Despite these limitations, the trends identified in this study are still expected to have useful implications for both clinical and research settings.

In the present study, the presentation level of the speech signal was 70 dB SPL as this has traditionally been the level, at which speech perception tests are presented (Waltzman, 2000). The high presentation level may have had limited value with these particular participants, who were all using the latest cochlear implant technology. Most cochlear implant users nowadays have access to spoken language at 60 dB SPL, and even 50 dB SPL, in certain communication environments (Firszt et al., 2004).

The speech perception test that was used in the present study was selected as it is the only known test specifically developed for children (Litovsky, 2003) with bilateral cochlear implants and as it was being considered for use in the Tygerberg Hospital / Stellenbosch University Cochlear Implant Programme. However, as it is a closed-set test, which is considered easy for today's cochlear implant users, the fixed presentation level and SNR may have further increased the incidence of a ceiling effect (Das & Buchman, 2005). Had the researcher used an adaptive SNR or obtained the SRT for each listening condition, the duration of testing would have been increased. This might have resulted in fatigue on the part of the participant, which could have subsequently affected the reliability of the results (Bailey, 1997). A compromise was decided on, thus the SNR of +5 dB was selected (Au et al., 2003).

The advantage of using a repeated measures single participant research design was that each participant served as his/her own control and a large sample size was not required (Hegde, 2003). Despite this benefit, it is important to note the limitations of this design. Firstly, the participants were tested numerous times, during a single visit, which could have led to fatigue, even though rest breaks were given to reduce the possibility of fatigue. Furthermore, in this study unilateral performance was compared to bilateral performance by asking the participant to switch the relevant cochlear implants off. Although this eliminated the need for controls, Dunn et al. (2008) feel that this testing protocol might not be completely appropriate as it involves testing bilateral listeners under conditions, which they do not use in their everyday lives (namely, monaural listening). It was assumed that these individuals would perform poorer in the unilateral conditions, possibly reflecting a more pronounced binaural benefit, because they were accustomed to wearing bilateral implants. This may have been a factor in some other studies (Gantz et al., 2002; Laszig et al., 2004; Schleich et al., 2004), which looked at post-lingually deafened adults, who may have had limited experience with unilateral cochlear implants. However, in the present study, all the participants had been successful unilateral cochlear implant users prior to receiving a second implant. It was, therefore, assumed that any binaural benefit observed would not be due to poor performance in the unilateral listening conditions as a result of limited unilateral experience.

The present study investigated speech perception in noise, which did not reflect the noise experienced in typical listening environments. The findings should, therefore, not be generalized to other listening situations, and conclusions with regards to the performance of the children in their everyday listening environments cannot be made.

6.2 CLINICAL IMPLICATIONS

Cochlear implant technology and candidacy have changed dramatically over the last 30 years. In response to the changes, the testing paradigms have needed to change. Although the use of open-set tests has increased, the presentation levels and stimulus complexity used do not appear to reflect the typical listening environment in the “real world” (Firszt et al., 2004). The findings of the present study suggest that the continued use of 70 dB SPL may not be appropriate, as it increases the risks of ceiling effects. It is recommended that more realistic presentation levels, either 50 or 60 dB SPL (Firszt et al., 2004) should be considered for clinical practice, as these may be better suited to assess the benefits gained from the use of bilateral cochlear implants.

The continued use of closed-set tests may be necessitated by the difficulties (e.g. floor effects) experienced with the use of open-set tests, particularly within the paediatric population. A difficulty with closed-set tests is the occurrence of ceiling effects (as observed during the present study). In clinical practice, where all tests do not have to take place during one visit, the use of adaptive or individually set SNRs should be considered (Dunn et al., 2005; Firszt et al., 2004). Further recommendations are that monosyllabic words be used instead of spondee words to increase the complexity of the stimuli (Lee & van Hasselt, 2005), or that a speech recognition threshold be obtained rather than a static score at a fixed presentation level.

The present study only studied one aspect of speech perception, namely, identification as described by Erber (1982). In the clinical setting, however, a test battery approach, which evaluates a range of speech perception abilities, as well as other auditory skills such as localisation, appears more advisable. The results of the present study indicate that available tests do not appear completely suitable for use with the new generation of bilateral implant users, as the test parameters may not be sensitive enough to reflect binaural benefits. New tests are, therefore, needed to accurately quantify all the benefits of bilateral cochlear implant use (Tyler et al., 2006), so that appropriate management plans, including rehabilitation strategies, are devised for each child (Ching et al., 2006).

6.3 IMPLICATIONS FOR FUTURE RESEARCH

The benefits of bilateral cochlear implants have been documented in a number of published studies. Limited research with regards to cochlear implants has been carried out in South Africa, and no research with regards to bilateral cochlear implants has been published.

Within a South African context, longitudinal studies may be more relevant as the numbers of children receiving bilateral cochlear implants, although increasing, still remains small due to the costs involved in obtaining and maintaining these implants. According to Murphy and O' Donoghue (2007), these types of studies may offset the limitations inherent in using a small heterogeneous sample.

As a developing country, South Africa has limited resources which have to be distributed equitably. In 2007, the Provincial Administration of the Western Cape subsidised the cost of six cochlear implants for unilateral implantation only (Mrs A.M. Muller, personal communication, July 15, 2008). Currently, an individual who requires a second implant has to bear the costs personally. Research investigating the cost-risk-benefit ratio of cochlear implants in general and bilateral implants in particular, is needed so that informed decisions can be made with respect to whether the benefits truly outweigh the costs and risks involved.

It would be interesting to see whether children, as well as parents and teachers, perceive any benefits of bilateral cochlear implants. These responses could then be compared with results obtained from objective performance measures. As can be seen in the present study, one participant did not perceive any benefit from the use of the second cochlear implant, despite obtaining a high score on the objective test. This information could be used in the clinical setting to motivate individuals who do not feel that they are benefiting from bilateral cochlear implants.

The present study looked at performance in noise, where only one noise source was activated at a time. Binaural benefits may not be evident under these simplistic conditions and conclusions drawn might not apply to performance in everyday listening situations. It would thus be useful to investigate speech perception performance in more complex listening conditions, such as multiple noise sources (Galvin et al., 2007; Ricketts et al., 2006).

On the basis of the present study, it is evident that more challenging speech perception tests are needed to meet the standards set by bilateral cochlear implants. There is an urgent need for the development of a comprehensive test battery for use with bilateral cochlear implants. Additional research is also needed to determine the limitations of existing tests when assessing the performance of bilaterally implanted children. The findings of these studies would help in the development of new tests or the modification of existing ones.

FINAL THOUGHT

The results of the present study highlight the need for suitable methods of evaluating performance with bilateral cochlear implants. If one is to justify the costs associated with bilateral implants, particularly in a country, whose average income is much less than the cost of one cochlear implant, evidence of binaural benefits needs to be provided. This cannot be achieved without appropriate measuring instruments.

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7. APPENDICES

Appendix A: Request to Committee for Human Research, Stellenbosch University, for ethical approval: Health Sciences

Gouwa Dawood

Department of Speech-Language and Hearing Therapy
Stellenbosch University
PO Box 19063
Tygerberg
7505
Tel: (w) 938 9494
Cell: 072 278 8022

Mr. van Tonder
Committee for Human Research
Stellenbosch University
PO Box 19063
Tygerberg
7505

Dear Sir

Re: Application for Registration of Research Project

I am currently enrolled in the Master's Programme, Department of Speech-Language and Hearing Therapy, at Stellenbosch University. One of the requirements of the course is that I complete a research project. I, therefore, wish to submit an application for the registration of this project.
For your perusal, attached, please find copies of the following:

- Research Proposal
- Protocol Synopsis
- Curriculum Vitae

A budget has not been included as the costs (which are mostly administrative in nature) will be covered by the investigator.
If further information is required, please do not hesitate to contact me.
Sincerely,

Gouwa Dawood
(Student number: 13236601)

Appendix B: Ethical approval from the Committee for Human Research, Stellenbosch University, to conduct the study:

UNIVERSITEIT·STELLENBOSCH·UNIVERSITY
jou kennisvennoot • your knowledge partner

13 April 2006

Mrs G Dawood
Discipline of Speech-Language and Hearing Therapy
Dept of Interdisciplinary Health Sciences

Dear Mrs Dawood

RESEARCH PROJECT: "SPEECH PERCEPTION WITH BILATERAL AND UNILATERAL COCHLEAR IMPLANTS IN QUIET AND IN NOISE"
PROJECT NUMBER : N06/01/001

At a meeting of the Committee for Human Research that was held on 7 February 2006 the above project was approved on condition that further information that was required, be submitted.

This information was supplied and the project was finally approved on 12 April 2006 **for a period of one year from this date**. This project is therefore now registered and you can proceed with the work. Please quote the above-mentioned project number in all further correspondence.

Please note that a progress report (obtainable on the website of our Division) should be submitted to the Committee before the year has expired. The Committee will then consider the continuation of the project for a further year (if necessary).

Patients participating in a research project in Tygerberg Hospital will not be treated free of charge as the Provincial Government of the Western Cape does not support research financially.

Due to heavy workload the nursing corps of the Tygerberg Hospital cannot offer comprehensive nursing care in research projects. It may therefore be expected of a research worker to arrange for private nursing care.

Yours faithfully

CJ VAN TONDER
RESEARCH DEVELOPMENT AND SUPPORT (TYGERBERG)
Tel: +27 21 938 9207 / E-mail: cjvt@sun.ac.za

CJVT/ev

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Fakulteit Gesondheidswetenskappe • Faculty of Health Sciences

Verbind tot Optimale Gesondheid • Committed to Optimal Health
Afdeling Navorsingsontwikkeling en -steun • Research Development and Support Division
Posbus/PO Box 19063 • Tygerberg 7505 • Suid-Afrika/South Africa
Tel: +27 21 938 9677 • Faks/Fax: +27 21 931 3352
E-pos/E-mail: rdsdinfo@sun.ac.za

Appendix C: Request to the Medical Superintendent, Tygerberg Hospital, for permission to conduct the study:

Dr A Muller
Medical Superintendent
Tygerberg Hospital
PO Box X1
Tygerberg
7505

Dear Dr Muller

Re: Permission to conduct research project

I am currently enrolled in the Master's Programme, Discipline of Speech-Language and Hearing Therapy, at Stellenbosch University. One of the requirements of the course is that I complete a research project. I, therefore, wish to request permission to conduct my research in the Cochlear Implant Programme.
The aim of the research is to compare the speech perception of children fitted with bilateral cochlear implants when they are using one or both of the implants in quiet and in noise. In order to do this, I will require access to patient information, as well as, the use of the Cochlear Implant facilities.

I have included the following documentation, for your perusal:

- Research Proposal
- Protocol Synopsis

If further information is required, please do not hesitate to contact me.
Sincerely,

Gouwa Dawood
(Student number: 13236601)

Prof. SK Tuomi
(Project supervisor)

Appendix D: Request to the Coordinator, Tygerberg Hospital / Stellenbosch University Cochlear implant Programme, for permission to conduct the study:

Mrs AMU Muller
Cochlear Implant Programme
Discipline of Speech-Language and Hearing Therapy
Stellenbosch University
PO Box 19063
Tygerberg
7505

Dear Mrs Muller

Re: Permission to conduct research project

I am currently enrolled in the Master's Programme, Discipline of Speech-Language and Hearing Therapy, at Stellenbosch University. One of the requirements of the course is that I complete a research project. I, therefore, wish to request permission to conduct my research in the Cochlear Implant Programme.
The aim of the research is to compare the speech perception of children fitted with bilateral cochlear implants when they are using one or both of the implants in quiet and in noise. In order to do this, I will require access to patient information, as well as, the use of the Cochlear Implant facilities.

I have included the following documentation, for your perusal:

- Research Proposal
- Protocol Synopsis

If further information is required, please do not hesitate to contact me.
Sincerely,

Gouwa Dawood
(Student number: 13236601)

Prof. SK Tuomi
(Project supervisor)

Appendix E: Information leaflet and consent form for parent/guardian of participant (English)

PARTICIPANT INFORMATION LEAFLET AND CONSENT FORM

TITLE OF THE RESEARCH PROJECT:

Speech Perception with Bilateral and Unilateral Cochlear Implants in Quiet and in Noise

REFERENCE NUMBER: NO6/01/001

PRINCIPLE INVESTIGATOR: **Gouwa Dawood**

SUPERVISORS: **Professor Seppo Tuomi and Ms Daleen Klop**

CO-SUPERVISOR: **Mrs Lida Müller**

ADDRESS:
Stellenbosch University
Department of Interdisciplinary Health Sciences
Discipline of Speech-Language and Hearing Therapy
PO Box 19063
Tygerberg
7505

CONTACT NUMBER: (021) 938 9741 / 9494

Dear Parent / Guardian

Your child is being invited to take part in a research project. Please take some time to read the information presented here, which will explain the details of this project. It is very important that you are fully satisfied that you clearly understand what this research entails and how your child could be involved. Your child's participation is **entirely voluntary** and you are free to decline to participate. If you say no, this will not affect you or your child negatively in any way whatsoever. You are also free to withdraw him/her from the study at any point, even if you do initially agree to let him/her take part.

This study has been approved by the Committee for Human Research at Stellenbosch University **and will be conducted according to the ethical guidelines and principles of the international Declaration of Helsinki, South African Guidelines for Good Clinical Practice and the Medical Research Council (MRC) Ethical Guidelines for Research.**

What is this research study all about?

Aims and Objectives: The aim of the study is to compare the speech perception of children fitted with bilateral cochlear implants when they are using one or both of the implants in quiet and in noise. Various studies have found that bilateral cochlear implant users understand speech better in noise, than unilateral cochlear implant users. Since a second cochlear implant involves extra expenses and medical risks, it is important to investigate the benefits of bilateral implants so that parents can make informed decisions with regards to obtaining a second cochlear implant for their child. Furthermore, there are currently no data available on the potential benefits of a second cochlear implant with South African cochlear implant users.

Test Procedures: Your child will be placed in a sound proof booth. A male voice will say some words, and your child will have to point to the picture that matches the word on a page containing four pictures. This process will be repeated until a list of twenty words has been completed. In total, six word lists will be presented to your child under different listening conditions (i.e. with one cochlear implant, with two cochlear implants, in quiet and in noise). All responses will be recorded and scored according to the number of correct responses obtained.

Processing of data: The investigator will convert the number of correct responses into percentages. The percentages obtained from the six word lists will be compared.

Why has your child been invited to participate?

All the children who are currently in the Stellenbosch University / Tygerberg Hospital Cochlear Implant Programme, who meet the following criteria, will be approached:

- Aged 3.5 years and older
- Received their cochlear implants in two separate operations
- Had their second cochlear implant activated at least 3 months prior to the study
- Use English or Afrikaans as their home language

What will your responsibilities be?

As a parent/guardian, your responsibility will be to bring your child to the appointed venue. The date and time will be arranged at your convenience.

Who will have access to information collected during this study?

All the information collected will be treated as confidential. Only the investigator and her supervisors will have access to any personal information. The identity of the participant will remain anonymous and participant names will, therefore, not be used in any publications or theses.

Is there any thing else that you should know or do?

- **You can contact the Committee for Human Research at 021-938 9207 if you have any concerns or complaints that have not been adequately addressed by the investigator**
- **You will receive a copy of this information and consent form for your own records**

Assent of minor

I (*Name of Child/Minor*)………………………………………………. have been invited to take part in the above research project.

- **The study investigator and my parents have explained the details of the study to me and I understand what they have said to me.**

- **They have also explained that this study will involve me sitting in a sound proof booth, listening to words. I will then be required to point to a picture that matches the word.**
- **I also know that I am free to withdraw from the study at any time if I am unhappy.**
- **By writing my name below, I voluntary agree to take part in this research project. I confirm that I have not been forced either by my parents or the study investigator to take part.**

..	**...**
Name of child	Independent witness
(To be written by the child if possible)	

Declaration by parent/legal guardian

By signing below, I *(name of parent/legal guardian)* …………………………….....……. agree to allow my child (name of child) ……………………………….… who is ………. years old, to take part in a research study entitled "Speech Perception with Bilateral and Unilateral Cochlear Implants in Quiet and in Noise".

I declare that:

- I have read or had read to me this information and consent form and that it is written in a language with which I am fluent and comfortable.
- I have had a chance to ask questions and all my questions have been adequately answered.
- I understand that taking part in this study is **voluntary** and I have not been pressurised to let my child take part.
- I may choose to withdraw my child from the study at any time and my child will not be penalised or prejudiced in any way.

- My child may be asked to leave the study before it has finished if the researcher feels it is in my child's best interests, or if my child does not follow the study plan as agreed to.

Signed at (*place*) ....…........…………….. on (*date*) ………………...……….. 2006.

....

Signature of parent/legal guardian   Signature of witness

Declaration by investigator

I, Gouwa Dawood, declare that:

- I explained the information in this document to:
    - *(name of child)* ………………..………..……………………………..
    - *(name of parent/ legal guardian)* ……………………………………...
- I encouraged the child and parent/legal guardian to ask questions and took adequate time to answer them.
- I am satisfied that the child and parent/legal guardian adequately understands all aspects of the research, as discussed above.
- I did not use a translator.

Signed at (*place*) ....…........…………….. on (*date*) …………………...……….. 2006.

....

Signature of investigator   Signature of witness

Appendix F: Information leaflet and consent form for parent/guardian of participant (Afrikaans)

DEELNEMERINLIGTINGSBLAD EN -TOESTEMMINGSVORM

TITEL VAN DIE NAVORSINGSPROJEK:

Spraakpersepsie met Bilaterale en Unilaterale Kogleêre Inplantings, in Stilte en in Geraas

VERWYSINGSNOMMER: NO6/01/001

HOOFNAVORSER: **Gouwa Dawood**

TOESIGHOUERS: **Professor Seppo Tuomi en Mev Daleen Klop**

MEDETOESIGHOUER: **Mev Lida Müller**

ADRES:

Universiteit van Stellenbosch
Departement Interdissiplinêre
Gesondheidswetenskap
Dissipline Spraak-Taal- en Gehoorterapie
Posbus 19063
Tygerberg
7505

KONTAKNOMMER: (021) 938 9741 / 9494

Geagter Ouer / Voog

U kind word genooi om deel te neem aan 'n navorsingsprojek. Lees asseblief hierdie inligtingsblad op u tyd deur aangesien die detail van die projek daarin verduidelik word. Dit is baie belangrik dat u ten volle moet verstaan wat die navorsing behels en hoe u kind daarby betrokke kan wees. U kind se deelname is ook **volkome vrywillig** en dit staan u vry om deelname te weier. U kind sal op geen wyse hoegenaamd negatief beïnvloed word indien u sou weier om hom/haar te laat deelneem nie. U mag u kind ook te eniger tyd aan die studie onttrek, selfs al het u ingestem om hom/haar te laat deelneem.

Hierdie studie is deur die Komitee vir Mensnavorsing van die Universiteit Stellenbosch **goedgekeur en sal uitgevoer word volgens die etiese riglyne en beginsels van die Internasionale Verklaring van Helsinki en die Etiese Riglyne vir Navorsing van die Mediese Navorsingsraad (MNR).**

<u>*Wat behels hierdie navorsingsprojek?*</u>

Doel: Die doel van die studie is om die spraakpersepsie van kinders wat met bilaterale kogleêre inplantings gepas is, te vergelyk wanner hulle een of albei inplantings in stilte en geraas gebruik. Verskeie studies het bevind dat bilaterale inplanting gebruikers spraak in geraas beter verstaan, as unilaterale inplanting gebruikers. Aangesien ‘n tweede kogleêre inplanting addisionele uitgawes en mediese risikos behels, is dit belangrik om die voordeel van bilaterale inplantings te ondersoek. Hierdie inligting kan gebruik word deur ouers sodat hulle ‘n ingeligde besluit kan neem met betrekking tot die aanskawing van ‘n tweede kogleêre inplanting vir hul kind. Bowendien, is daar huidiglik geen data oor die potensiale voordele van ‘n tweede kogleêre inplanting met Suid Afrikaanse inplantings gebruikers nie.

Toetsprosedure: U kind sal in ‘n klankdigde kamer geplaas word. Woorde sal deur ‘n mans stem gesê word en u kind sal na die prentjie wat by die gesproke woord pas, moet wys. Elke bladsy sal ‘n keuse van vier prentjies bevat. Hierdie proses sal herhaal word totdat ‘n lys van twintig woorde voltooi is. ‘n Totaal van ses lyste, onder verskillende luister-toestande (nl. met een kogleêre inplanting, met twee inplantings, in stilte en in geraas). Alle antwoorde sal opgeteken word. Die telling sal uitgewerk word, volgens die hoeveelheid korrek antwoorde.

Verwerking van data: Die navorser sal die getal korrekte antwoorde tot ‘n persentasie verander. Die persentasies wat van die ses lyste verkry is, sal vergelyk word.

Waarom is u kind genooi om deel te neem?

Al die kinders wat huidiglik die Universiteit van Stellenbosch / Tygerberg Hospitaal Kogleêre Inplantings Program bywoon, en wat oor die volgende kriteria beskik, is genader:

- 3.5 jaar oud en ouer
- Het hul kogleêre inplantings in twee aparte operasies ontvang
- Die aanskakeling van die tweede inplanting was ten minste 3 maande voor hierdie studie
- Gebruik Engels of Afrikaans as hul huistaal

Wat sal u verantwoordelikhede wees?

As die ouer/voog, is dit u verantwoordelik om u kind na die afgesproke plek te bring. ‘n Geskikte datum en tyd sal met u gereël word.

Sal u kind voordeel trek deur deel te neem aan hierdie navorsing?

Daar is geen persoonlike of finansiele bate vir u of u kind is nie, as u in die studie deelneem nie, maar die onderneming van hierdie studie sal die voordele van bilaterale kogleêre inplantings ondersoek. Die resultate wat verkry word sal beskikbaar wees vir ander ouers wat ’n besluit moet neem oor die voordeel van bilaterale inplantings vir hul spesifieke kinders.

Wie sal toegang hê tot u kind se mediese rekords?

Al die inligting wat verkry word, sal as konfidentiele inligting behandel word. Net die navorser en haar toesighouers sal toegang hê tot presoonlike inligting. Die identiteit van die deelnemers sal anoniem bly, dus sal hul name nie in enige publikasie of tese verskyn nie.

Is daar enigiets anders wat u moet weet of doen?

- **U kan die Komitee vir Mensnavorsing kontak by 021-938 9207 indien u enige bekommernis of klagte het wat nie bevredigend deur die navorser hanteer is nie.**

- **U sal ’n afskrif van hierdie inligtings- en toestemmingsvorm ontvang vir u eie rekords.**

Instemming van minderjarige

Ek (*naam van kind/minderjarige*) ………………………………..................……………. is genooi om deel te neem aan bogenoemde navorsingsprojek.

- **Die navorser en my ouers het die besonderhede van bogenoemde navorsingsprojek aan my verduidelik en ek verstaan wat hulle aan my gesê het.**
- **Hulle het ook aan my verduidelik dat die projek die volgende insluit: Ek sal in ‘n klankdig kamer sit en na woorde luister. Ek sal dan na die prentjie wat by die woord pas, wys.**
- **Ek weet ook dat ek te eniger tyd aan die navorsingsprojek kan onttrek indien ek ongelukkig is.**
- **Deur my naam hieronder in te vul, onderneem ek om** vrywillig **aan die navorsingsprojek deel te neem. Ek bevestig ook dat ek nie deur my ouers of navorser gedwing is om deel te neem nie.**

...	**..**
Naam van kind	Onafhanklike getuie
(Deur kind geskryf te word indien moontlik)	

Verklaring deur ouer/wettige voog

Met die ondertekening van hierdie dokument onderneem ek, (*naam van ouer/wettige voog*) …………..….., om my kind *(naam van kind)* …………..….., wat .... jaar oud is, te laat deelneem aan ’n navorsingsprojek getiteld “Spraakpersepsie met Bilaterale en Unilaterale Kogleêre Inplantings, in Stilte en in Geraas”.

Ek verklaar dat:

- Ek hierdie inligtings- en toestemmingsvorm gelees het of aan my laat voorlees het en dat dit in ’n taal geskryf is waarin ek vaardig en gemaklik mee is.
- Ek geleentheid gehad het om vrae te stel en dat al my vrae bevredigend beantwoord is.
- Ek verstaan dat deelname aan hierdie projek **vrywillig** is en dat daar geen druk op my geplaas is om my kind te laat deelneem nie.
- My kind te eniger tyd aan die projek mag onttrek en dat hy/sy nie op enige wyse daardeur benadeel sal word nie.
- My kind gevra mag word om aan die projek te onttrek voordat dit afgehandel is indien die navorser van oordeel is dat dit in sy/haar beste belang is, of indien my kind nie die ooreengekome studieplan volg nie.

Geteken te (*plek*) ....…………….. op (*datum*) …………...……….. 2005.

....

Handtekening van ouer/wettige voog Handtekening van getuie

Verklaring deur navorser

Ek, Gouwa Dawood, verklaar dat:

- Ek die inligting in hierdie dokument verduidelik het aan:
  - (*naam van kind)*..
  - *(naam van ouer/wettige voog)*..
- Ek die kind en/of ouer/wettige voog aangemoedig het om vrae te vra en voldoende tyd gebruik het om dit te beantwoord.

- Ek tevrede is dat die kind en/of ouer/wettige voog al die aspekte van die navorsingsprojek soos hierbo bespreek, voldoende verstaan.
- Ek het nie ’n tolk gebruik het nie.

Geteken te (*plek*) ....…………….. op (*datum*) …………...……….. 2006.

....

Handtekening van navorser Handtekening van getuie

Appendix G1: CRISP response form – List 1 (English)

CRISP SPONDEES
BOOK 1: LIST 1 (TRACK #2)
PATIENT:________________________________ DATE:__________
TEST CONDITIONS:____

TRIAL #:	CIRCLE PATIENT'S RESPONSE BELOW				TARGET:
1	PLAYGROUND	BEDROOM	DOLLSHOUSE	TOOTHBRUSH	**PLAYGROUND**
2	BATHTUB	CUPCAKE	EYEBROW	BIRTHDAY	**EYEBROW**
3	PEACOCK	MUSHROOM	RAINBOW	HAIRBRUSH	**PEACOCK**
4	BEDROOM	TEAPOT	MILKSHAKE	BIRDNEST	**TEAPOT**
5	BATHTUB	BIRDNEST	SEAGULL	OUTSIDE	**SEAGULL**
6	EYEBROW	ICECREAM	RAINBOW	TOOTHBRUSH	**ICECREAM**
7	MUSHROOM	DOLLSHOUSE	SHOELACE	HOTDOG	**HOTDOG**
8	BATHTUB	SEAGULL	BEDROOM	PLAYGROUND	**BEDROOM**
9	TOOTHBRUSH	SEAGULL	SHOELACE	GOLDFISH	**GOLDFISH**
10	OUTSIDE	HAIRBRUSH	TEAPOT	SEAGULL	**SEAGULL**
11	SHOELACE	HOTDOG	GOLDFISH	TEAPOT	**GOLDFISH**
12	T-SHIRT	TEAPOT	CUPCAKE	DOLLSHOUSE	**DOLLSHOUSE**
13	PEACOCK	EYEBROW	BIRDNEST	SUNSHINE	**BIRDNEST**
14	RAINBOW	BEDROOM	SUITCASE	CUPCAKE	**RAINBOW**
15	RAINBOW	EYEBROW	GOLDFISH	BIRTHDAY	**BIRTHDAY**
16	MILKSHAKE	BIRDNEST	CELLPHONE	GOLDFISH	**CELLPHONE**
17	MUSHROOM	SUITCASE	MILKSHAKE	CELLPHONE	**MUSHROOM**
18	CELLPHONE	SHOELACE	HOTDOG	PLAYGROUND	**SHOELACE**
19	CELLPHONE	MILKSHAKE	MUSHROOM	ICECREAM	**CELLPHONE**
20	ICECREAM	CUPCAKE	PEACOCK	TOOTHBRUSH	**CUPCAKE**
21	PEACOCK	BATHTUB	SUNSHINE	T-SHIRT	**BATHTUB**
22	SUNSHINE	T-SHIRT	OUTSIDE	HOTDOG	**T-SHIRT**
23	SUITCASE	OUTSIDE	HAIRBRUSH	T-SHIRT	**T-SHIRT**
24	ICECREAM	BIRTHDAY	PLAYGROUND	SUNSHINE	**ICECREAM**
25	BIRTHDAY	HAIRBRUSH	DOLLSHOUSE	SUITCASE	**HAIRBRUSH**

Appendix G2: CRISP Response form – List 2 (English)

CRISP SPONDEES
BOOK 1: LIST 2 (TRACK #3)
PATIENT:________________________________ **DATE:**__________
TEST CONDITIONS:____

TRIAL #:	CIRCLE PATIENT'S RESPONSE BELOW				TARGET:
1	PLAYGROUND	BEDROOM	DOLLSHOUSE	TOOTHBRUSH	**BEDROOM**
2	BATHTUB	CUPCAKE	EYEBROW	BIRTHDAY	**BATHTUB**
3	PEACOCK	MUSHROOM	RAINBOW	HAIRBRUSH	**HAIRBRUSH**
4	BEDROOM	TEAPOT	MILKSHAKE	BIRDNEST	**MILKSHAKE**
5	BATHTUB	BIRDNEST	SEAGULL	OUTSIDE	**SEAGULL**
6	EYEBROW	ICECREAM	RAINBOW	TOOTHBRUSH	**RAINBOW**
7	MUSHROOM	DOLLSHOUSE	SHOELACE	HOTDOG	**SHOELACE**
8	BATHTUB	SEAGULL	BEDROOM	PLAYGROUND	**PLAYGROUND**
9	TOOTHBRUSH	SEAGULL	SHOELACE	GOLDFISH	**SHOELACE**
10	OUTSIDE	HAIRBRUSH	TEAPOT	SEAGULL	**TEAPOT**
11	SHOELACE	HOTDOG	GOLDFISH	TEAPOT	**SHOELACE**
12	T-SHIRT	TEAPOT	CUPCAKE	DOLLSHOUSE	**CUPCAKE**
13	PEACOCK	EYEBROW	BIRDNEST	SUNSHINE	**BIRDNEST**
14	RAINBOW	BEDROOM	SUITCASE	CUPCAKE	**CUPCAKE**
15	RAINBOW	EYEBROW	GOLDFISH	BIRTHDAY	**EYEBROW**
16	MILKSHAKE	BIRDNEST	CELLPHONE	GOLDFISH	**GOLDFISH**
17	MUSHROOM	SUITCASE	MILKSHAKE	CELLPHONE	**MILKSHAKE**
18	CELLPHONE	SHOELACE	HOTDOG	PLAYGROUND	**PLAYGROUND**
19	CELLPHONE	MILKSHAKE	MUSHROOM	ICECREAM	**MILKSHAKE**
20	ICECREAM	CUPCAKE	PEACOCK	TOOTHBRUSH	**TOOTHBRUSH**
21	PEACOCK	BATHTUB	SUNSHINE	T-SHIRT	**BATHTUB**
22	SUNSHINE	T-SHIRT	OUTSIDE	HOTDOG	**HOTDOG**
23	SUITCASE	OUTSIDE	HAIRBRUSH	T-SHIRT	**T-SHIRT**
24	ICECREAM	BIRTHDAY	PLAYGROUND	SUNSHINE	**SUNSHINE**
25	BIRTHDAY	HAIRBRUSH	DOLLSHOUSE	SUITCASE	**BIRTHDAY**

Appendix G3: CRISP response form – List 3 (English)

CRISP SPONDEES
BOOK 1: LIST 3 (TRACK #4)
PATIENT:________________________________ **DATE:**__________
TEST CONDITIONS:____

TRIAL #:	CIRCLE PATIENT'S RESPONSE BELOW				TARGET:
1	PLAYGROUND	BEDROOM	DOLLSHOUSE	TOOTHBRUSH	DOLLSHOUSE
2	BATHTUB	CUPCAKE	EYEBROW	BIRTHDAY	BATHTUB
3	PEACOCK	MUSHROOM	RAINBOW	HAIRBRUSH	HAIRBRUSH
4	BEDROOM	TEAPOT	MILKSHAKE	BIRDNEST	BEDROOM
5	BATHTUB	BIRDNEST	SEAGULL	OUTSIDE	BATHTUB
6	EYEBROW	ICECREAM	RAINBOW	TOOTHBRUSH	ICECREAM
7	MUSHROOM	DOLLSHOUSE	SHOELACE	HOTDOG	HOTDOG
8	BATHTUB	SEAGULL	BEDROOM	PLAYGROUND	SEAGULL
9	TOOTHBRUSH	SEAGULL	SHOELACE	GOLDFISH	SEAGULL
10	OUTSIDE	HAIRBRUSH	TEAPOT	SEAGULL	HAIRBRUSH
11	SHOELACE	HOTDOG	GOLDFISH	TEAPOT	GOLDFISH
12	T-SHIRT	TEAPOT	CUPCAKE	DOLLSHOUSE	TEAPOT
13	PEACOCK	EYEBROW	BIRDNEST	SUNSHINE	SUNSHINE
14	RAINBOW	BEDROOM	SUITCASE	CUPCAKE	CUPCAKE
15	RAINBOW	EYEBROW	GOLDFISH	BIRTHDAY	RAINBOW
16	MILKSHAKE	BIRDNEST	CELLPHONE	GOLDFISH	CELLPHONE
17	MUSHROOM	SUITCASE	MILKSHAKE	CELLPHONE	SUITCASE
18	CELLPHONE	SHOELACE	HOTDOG	PLAYGROUND	PLAYGROUND
19	CELLPHONE	MILKSHAKE	MUSHROOM	ICECREAM	MILKSHAKE
20	ICECREAM	CUPCAKE	PEACOCK	TOOTHBRUSH	CUPCAKE
21	PEACOCK	BATHTUB	SUNSHINE	T-SHIRT	SUNSHINE
22	SUNSHINE	T-SHIRT	OUTSIDE	HOTDOG	OUTSIDE
23	SUITCASE	OUTSIDE	HAIRBRUSH	T-SHIRT	SUITCASE
24	ICECREAM	BIRTHDAY	PLAYGROUND	SUNSHINE	PLAYGROUND
25	BIRTHDAY	HAIRBRUSH	DOLLSHOUSE	SUITCASE	BIRTHDAY

Appendix G4: CRISP response form – List 4 (English)

CRISP SPONDEES
BOOK 1: LIST 4 (TRACK #5)
PATIENT:_______________________________ **DATE:**__________
TEST CONDITIONS:_______________________________________

TRIAL #:	CIRCLE PATIENT'S RESPONSE BELOW				TARGET:
1	PLAYGROUND	BEDROOM	DOLLSHOUSE	TOOTHBRUSH	**BEDROOM**
2	BATHTUB	CUPCAKE	EYEBROW	BIRTHDAY	**EYEBROW**
3	PEACOCK	MUSHROOM	RAINBOW	HAIRBRUSH	**PEACOCK**
4	BEDROOM	TEAPOT	MILKSHAKE	BIRDNEST	**BIRDNEST**
5	BATHTUB	BIRDNEST	SEAGULL	OUTSIDE	**OUTSIDE**
6	EYEBROW	ICECREAM	RAINBOW	TOOTHBRUSH	**ICECREAM**
7	MUSHROOM	DOLLSHOUSE	SHOELACE	HOTDOG	**DOLLSHOUSE**
8	BATHTUB	SEAGULL	BEDROOM	PLAYGROUND	**SEAGULL**
9	TOOTHBRUSH	SEAGULL	SHOELACE	GOLDFISH	**SHOELACE**
10	OUTSIDE	HAIRBRUSH	TEAPOT	SEAGULL	**SEAGULL**
11	SHOELACE	HOTDOG	GOLDFISH	TEAPOT	**TEAPOT**
12	T-SHIRT	TEAPOT	CUPCAKE	DOLLSHOUSE	**DOLLSHOUSE**
13	PEACOCK	EYEBROW	BIRDNEST	SUNSHINE	**BIRDNEST**
14	RAINBOW	BEDROOM	SUITCASE	CUPCAKE	**CUPCAKE**
15	RAINBOW	EYEBROW	GOLDFISH	BIRTHDAY	**RAINBOW**
16	MILKSHAKE	BIRDNEST	CELLPHONE	GOLDFISH	**MILKSHAKE**
17	MUSHROOM	SUITCASE	MILKSHAKE	CELLPHONE	**SUITCASE**
18	CELLPHONE	SHOELACE	HOTDOG	PLAYGROUND	**PLAYGROUND**
19	CELLPHONE	MILKSHAKE	MUSHROOM	ICECREAM	**MUSHROOM**
20	ICECREAM	CUPCAKE	PEACOCK	TOOTHBRUSH	**CUPCAKE**
21	PEACOCK	BATHTUB	SUNSHINE	T-SHIRT	**PEACOCK**
22	SUNSHINE	T-SHIRT	OUTSIDE	HOTDOG	**HOTDOG**
23	SUITCASE	OUTSIDE	HAIRBRUSH	T-SHIRT	**HAIRBRUSH**
24	ICECREAM	BIRTHDAY	PLAYGROUND	SUNSHINE	**BIRTHDAY**
25	BIRTHDAY	HAIRBRUSH	DOLLSHOUSE	SUITCASE	**SUITCASE**

Appendix G5: CRISP response form – List 5 (English)

CRISP SPONDEES
BOOK 1: LIST 5 (TRACK #6)
PATIENT:________________________________ **DATE:**__________
TEST CONDITIONS:____

TRIAL #:	CIRCLE PATIENT'S RESPONSE BELOW				TARGET:
1	PLAYGROUND	BEDROOM	DOLLSHOUSE	TOOTHBRUSH	BEDROOM
2	BATHTUB	CUPCAKE	EYEBROW	BIRTHDAY	CUPCAKE
3	PEACOCK	MUSHROOM	RAINBOW	HAIRBRUSH	HAIRBRUSH
4	BEDROOM	TEAPOT	MILKSHAKE	BIRDNEST	BEDROOM
5	BATHTUB	BIRDNEST	SEAGULL	OUTSIDE	SEAGULL
6	EYEBROW	ICECREAM	RAINBOW	TOOTHBRUSH	EYEBROW
7	MUSHROOM	DOLLSHOUSE	SHOELACE	HOTDOG	HOTDOG
8	BATHTUB	SEAGULL	BEDROOM	PLAYGROUND	BATHTUB
9	TOOTHBRUSH	SEAGULL	SHOELACE	GOLDFISH	TOOTHBRUSH
10	OUTSIDE	HAIRBRUSH	TEAPOT	SEAGULL	HAIRBRUSH
11	SHOELACE	HOTDOG	GOLDFISH	TEAPOT	HOTDOG
12	T-SHIRT	TEAPOT	CUPCAKE	DOLLSHOUSE	CUPCAKE
13	PEACOCK	EYEBROW	BIRDNEST	SUNSHINE	PEACOCK
14	RAINBOW	BEDROOM	SUITCASE	CUPCAKE	BEDROOM
15	RAINBOW	EYEBROW	GOLDFISH	BIRTHDAY	EYEBROW
16	MILKSHAKE	BIRDNEST	CELLPHONE	GOLDFISH	CELLPHONE
17	MUSHROOM	SUITCASE	MILKSHAKE	CELLPHONE	CELLPHONE
18	CELLPHONE	SHOELACE	HOTDOG	PLAYGROUND	PLAYGROUND
19	CELLPHONE	MILKSHAKE	MUSHROOM	ICECREAM	ICECREAM
20	ICECREAM	CUPCAKE	PEACOCK	TOOTHBRUSH	ICECREAM
21	PEACOCK	BATHTUB	SUNSHINE	T-SHIRT	SUNSHINE
22	SUNSHINE	T-SHIRT	OUTSIDE	HOTDOG	SUNSHINE
23	SUITCASE	OUTSIDE	HAIRBRUSH	T-SHIRT	T-SHIRT
24	ICECREAM	BIRTHDAY	PLAYGROUND	SUNSHINE	SUNSHINE
25	BIRTHDAY	HAIRBRUSH	DOLLSHOUSE	SUITCASE	BIRTHDAY

Appendix G6: CRISP response form – List 6 (English)

CRISP SPONDEES
BOOK 1: LIST 6 (TRACK #7)
PATIENT:____________________ **DATE:**__________
TEST CONDITIONS:____________________

TRIAL #:	CIRCLE PATIENT'S RESPONSE BELOW				TARGET:
1	PLAYGROUND	BEDROOM	DOLLSHOUSE	TOOTHBRUSH	BEDROOM
2	BATHTUB	CUPCAKE	EYEBROW	BIRTHDAY	CUPCAKE
3	PEACOCK	MUSHROOM	RAINBOW	HAIRBRUSH	PEACOCK
4	BEDROOM	TEAPOT	MILKSHAKE	BIRDNEST	MILKSHAKE
5	BATHTUB	BIRDNEST	SEAGULL	OUTSIDE	SEAGULL
6	EYEBROW	ICECREAM	RAINBOW	TOOTHBRUSH	ICECREAM
7	MUSHROOM	DOLLSHOUSE	SHOELACE	HOTDOG	HOTDOG
8	BATHTUB	SEAGULL	BEDROOM	PLAYGROUND	BEDROOM
9	TOOTHBRUSH	SEAGULL	SHOELACE	GOLDFISH	SEAGULL
10	OUTSIDE	HAIRBRUSH	TEAPOT	SEAGULL	TEAPOT
11	SHOELACE	HOTDOG	GOLDFISH	TEAPOT	TEAPOT
12	T-SHIRT	TEAPOT	CUPCAKE	DOLLSHOUSE	T-SHIRT
13	PEACOCK	EYEBROW	BIRDNEST	SUNSHINE	EYEBROW
14	RAINBOW	BEDROOM	SUITCASE	CUPCAKE	RAINBOW
15	RAINBOW	EYEBROW	GOLDFISH	BIRTHDAY	BIRTHDAY
16	MILKSHAKE	BIRDNEST	CELLPHONE	GOLDFISH	MILKSHAKE
17	MUSHROOM	SUITCASE	MILKSHAKE	CELLPHONE	MILKSHAKE
18	CELLPHONE	SHOELACE	HOTDOG	PLAYGROUND	SHOELACE
19	CELLPHONE	MILKSHAKE	MUSHROOM	ICECREAM	ICECREAM
20	ICECREAM	CUPCAKE	PEACOCK	TOOTHBRUSH	PEACOCK
21	PEACOCK	BATHTUB	SUNSHINE	T-SHIRT	SUNSHINE
22	SUNSHINE	T-SHIRT	OUTSIDE	HOTDOG	OUTSIDE
23	SUITCASE	OUTSIDE	HAIRBRUSH	T-SHIRT	OUTSIDE
24	ICECREAM	BIRTHDAY	PLAYGROUND	SUNSHINE	ICECREAM
25	BIRTHDAY	HAIRBRUSH	DOLLSHOUSE	SUITCASE	SUITCASE

Appendix G7: CRISP response form – List 7 (English)

CRISP SPONDEES
BOOK 1: LIST 7 (TRACK #8)
PATIENT:______________________________________ **DATE:**___________
TEST CONDITIONS:____

TRIAL #:	CIRCLE PATIENT'S RESPONSE BELOW				TARGET:
1	PLAYGROUND	BEDROOM	DOLLSHOUSE	TOOTHBRUSH	PLAYGROUND
2	BATHTUB	CUPCAKE	EYEBROW	BIRTHDAY	CUPCAKE
3	PEACOCK	MUSHROOM	RAINBOW	HAIRBRUSH	HAIRBRUSH
4	BEDROOM	TEAPOT	MILKSHAKE	BIRDNEST	MILKSHAKE
5	BATHTUB	BIRDNEST	SEAGULL	OUTSIDE	OUTSIDE
6	EYEBROW	ICECREAM	RAINBOW	TOOTHBRUSH	RAINBOW
7	MUSHROOM	DOLLSHOUSE	SHOELACE	HOTDOG	DOLLSHOUSE
8	BATHTUB	SEAGULL	BEDROOM	PLAYGROUND	PLAYGROUND
9	TOOTHBRUSH	SEAGULL	SHOELACE	GOLDFISH	GOLDFISH
10	OUTSIDE	HAIRBRUSH	TEAPOT	SEAGULL	SEAGULL
11	SHOELACE	HOTDOG	GOLDFISH	TEAPOT	TEAPOT
12	T-SHIRT	TEAPOT	CUPCAKE	DOLLSHOUSE	T-SHIRT
13	PEACOCK	EYEBROW	BIRDNEST	SUNSHINE	PEACOCK
14	RAINBOW	BEDROOM	SUITCASE	CUPCAKE	CUPCAKE
15	RAINBOW	EYEBROW	GOLDFISH	BIRTHDAY	RAINBOW
16	MILKSHAKE	BIRDNEST	CELLPHONE	GOLDFISH	MILKSHAKE
17	MUSHROOM	SUITCASE	MILKSHAKE	CELLPHONE	SUITCASE
18	CELLPHONE	SHOELACE	HOTDOG	PLAYGROUND	CELLPHONE
19	CELLPHONE	MILKSHAKE	MUSHROOM	ICECREAM	MILKSHAKE
20	ICECREAM	CUPCAKE	PEACOCK	TOOTHBRUSH	PEACOCK
21	PEACOCK	BATHTUB	SUNSHINE	T-SHIRT	PEACOCK
22	SUNSHINE	T-SHIRT	OUTSIDE	HOTDOG	SUNSHINE
23	SUITCASE	OUTSIDE	HAIRBRUSH	T-SHIRT	T-SHIRT
24	ICECREAM	BIRTHDAY	PLAYGROUND	SUNSHINE	PLAYGROUND
25	BIRTHDAY	HAIRBRUSH	DOLLSHOUSE	SUITCASE	SUITCASE

Appendix G8: CRISP response form – List 8 (English)

CRISP SPONDEES
BOOK 1: LIST 8 (TRACK #9)
PATIENT:________________________________ **DATE:**__________
TEST CONDITIONS:____

TRIAL #:	CIRCLE PATIENT'S RESPONSE BELOW				TARGET:
1	PLAYGROUND	BEDROOM	DOLLSHOUSE	TOOTHBRUSH	BEDROOM
2	BATHTUB	CUPCAKE	EYEBROW	BIRTHDAY	BIRTHDAY
3	PEACOCK	MUSHROOM	RAINBOW	HAIRBRUSH	MUSHROOM
4	BEDROOM	TEAPOT	MILKSHAKE	BIRDNEST	TEAPOT
5	BATHTUB	BIRDNEST	SEAGULL	OUTSIDE	BATHTUB
6	EYEBROW	ICECREAM	RAINBOW	TOOTHBRUSH	TOOTHBRUSH
7	MUSHROOM	DOLLSHOUSE	SHOELACE	HOTDOG	SHOELACE
8	BATHTUB	SEAGULL	BEDROOM	PLAYGROUND	BATHTUB
9	TOOTHBRUSH	SEAGULL	SHOELACE	GOLDFISH	SEAGULL
10	OUTSIDE	HAIRBRUSH	TEAPOT	SEAGULL	SEAGULL
11	SHOELACE	HOTDOG	GOLDFISH	TEAPOT	SHOELACE
12	T-SHIRT	TEAPOT	CUPCAKE	DOLLSHOUSE	CUPCAKE
13	PEACOCK	EYEBROW	BIRDNEST	SUNSHINE	EYEBROW
14	RAINBOW	BEDROOM	SUITCASE	CUPCAKE	SUITCASE
15	RAINBOW	EYEBROW	GOLDFISH	BIRTHDAY	BIRTHDAY
16	MILKSHAKE	BIRDNEST	CELLPHONE	GOLDFISH	BIRDNEST
17	MUSHROOM	SUITCASE	MILKSHAKE	CELLPHONE	CELLPHONE
18	CELLPHONE	SHOELACE	HOTDOG	PLAYGROUND	HOTDOG
19	CELLPHONE	MILKSHAKE	MUSHROOM	ICECREAM	MUSHROOM
20	ICECREAM	CUPCAKE	PEACOCK	TOOTHBRUSH	TOOTHBRUSH
21	PEACOCK	BATHTUB	SUNSHINE	T-SHIRT	PEACOCK
22	SUNSHINE	T-SHIRT	OUTSIDE	HOTDOG	T-SHIRT
23	SUITCASE	OUTSIDE	HAIRBRUSH	T-SHIRT	T-SHIRT
24	ICECREAM	BIRTHDAY	PLAYGROUND	SUNSHINE	ICECREAM
25	BIRTHDAY	HAIRBRUSH	DOLLSHOUSE	SUITCASE	HAIRBRUSH

Appendix H1: CRISP response form – List 1 (Afrikaans)

CRISP SPONDEES
BOOK 1: LIST 1 (TRACK #2)
PATIENT:__________________________________ **DATE:**__________
TEST CONDITIONS:____

TRIAL #:	CIRCLE PATIENT'S RESPONSE BELOW				TARGET:
1	BOEKRAK	YSKAS	GLYPLANK	POSBUS	**GLYPLANK**
2	VOELNES	POSBUS	KOELDRANK	REENJAS	**KOELDRANK**
3	SKILPAD	BOOMSTAM	KLEINGELD	VERFKWAS	**BOOMSTAM**
4	HANDSAK	VLIEGTUIG	SKILPAD	POSBUS	**HANDSAK**
5	YSKAS	REENBOOG	VOELNES	SONSKYN	**REENBOOG**
6	KOELDRANK	WASBAK	SONSKYN	VERFKWAS	**WASBAK**
7	SPEELGOED	POTLOOD	BLOMPOT	BOOMSTAM	**SPEELGOED**
8	SONBRIL	BLOMPOT	POSBUS	POTLOOD	**BLOMPOT**
9	ROOMYS	VOORDEUR	BLOMPOT	REENBOOG	**VOORDEUR**
10	BOOMSTAM	ROOMYS	SPEELGOED	REENBOOG	**SPEELGOED**
11	VERFKWAS	KOELDRANK	HANDSAK	LANGBROEK	**LANGBROEK**
12	WASBAK	KLEINGELD	VLIEGTUIG	GLYPLANK	**VLIEGTUIG**
13	VLIEGTUIG	ROOMYS	SPEELGOED	GLYPLANK	**ROOMYS**
14	VOELNES	POTLOOD	REENBOOG	VERFKWAS	**REENBOOG**
15	DEURKNOP	LANGBROEK	BOEKRAK	REENJAS	**BOEKRAK**
16	SONSKYN	REENJAS	SPRINGTOU	SONBRIL	**SPRINGTOU**
17	SPRINGTOU	VOELNES	VOORDEUR	WASBAK	**WASBAK**
18	ROOMYS	WASBAK	POTLOOD	SKILPAD	**WASBAK**
19	HANDSAK	VOORDEUR	KOELDRANK	BOEKRAK	**VOORDEUR**
20	SONBRIL	SPEELGOED	DEURKNOP	REENJAS	**SPEELGOED**
21	SONBRIL	SPRINGTOU	KLEINGELD	BOEKRAK	**SPRINGTOU**
22	YSKAS	BLOMPOT	SPRINGTOU	DEURKNOP	**BLOMPOT**
23	KLEINGELD	HANDSAK	YSKAS	SONSKYN	**SONSKYN**
24	GLYPLANK	LANGBROEK	VOORDEUR	DEURKNOP	**DEURKNOP**
25	LANGBROEK	BOOMSTAM	VLIEGTUIG	SKILPAD	**LANGBROEK**

Appendix H2: CRISP response form – List 2 (Afrikaans)

CRISP SPONDEES
BOOK 1: LIST 2 (TRACK #3)
PATIENT:____________________________________ DATE:___________
TEST CONDITIONS:____

TRIAL #:	CIRCLE PATIENT'S RESPONSE BELOW				TARGET:
1	BOEKRAK	YSKAS	GLYPLANK	POSBUS	**BOEKRAK**
2	VOELNES	POSBUS	KOELDRANK	REENJAS	**POSBUS**
3	SKILPAD	BOOMSTAM	KLEINGELD	VERFKWAS	**VERFKWAS**
4	HANDSAK	VLIEGTUIG	SKILPAD	POSBUS	**SKILPAD**
5	YSKAS	REENBOOG	VOELNES	SONSKYN	**SONSKYN**
6	KOELDRANK	WASBAK	SONSKYN	VERFKWAS	**SONSKYN**
7	SPEELGOED	POTLOOD	BLOMPOT	BOOMSTAM	**SPEELGOED**
8	SONBRIL	BLOMPOT	POSBUS	POTLOOD	**POTLOOD**
9	ROOMYS	VOORDEUR	BLOMPOT	REENBOOG	**ROOMYS**
10	BOOMSTAM	ROOMYS	SPEELGOED	REENBOOG	**ROOMYS**
11	VERFKWAS	KOELDRANK	HANDSAK	LANGBROEK	**LANGBROEK**
12	WASBAK	KLEINGELD	VLIEGTUIG	GLYPLANK	**WASBAK**
13	VLIEGTUIG	ROOMYS	SPEELGOED	GLYPLANK	**GLYPLANK**
14	VOELNES	POTLOOD	REENBOOG	VERFKWAS	**POTLOOD**
15	DEURKNOP	LANGBROEK	BOEKRAK	REENJAS	**REENJAS**
16	SONSKYN	REENJAS	SPRINGTOU	SONBRIL	**SONBRIL**
17	SPRINGTOU	VOELNES	VOORDEUR	WASBAK	**VOELNES**
18	ROOMYS	WASBAK	POTLOOD	SKILPAD	**POTLOOD**
19	HANDSAK	VOORDEUR	KOELDRANK	BOEKRAK	**VOORDEUR**
20	SONBRIL	SPEELGOED	DEURKNOP	REENJAS	**REENJAS**
21	SONBRIL	SPRINGTOU	KLEINGELD	BOEKRAK	**KLEINGELD**
22	YSKAS	BLOMPOT	SPRINGTOU	DEURKNOP	**SPRINGTOU**
23	KLEINGELD	HANDSAK	YSKAS	SONSKYN	**KLEINGELD**
24	GLYPLANK	LANGBROEK	VOORDEUR	DEURKNOP	**GLYPLANK**
25	LANGBROEK	BOOMSTAM	VLIEGTUIG	SKILPAD	**VLIEGTUIG**

Appendix H3: CRISP response form – List 3 (Afrikaans)

CRISP SPONDEES
BOOK 1: LIST 3 (TRACK #4)
PATIENT:______________________________ DATE:__________
TEST CONDITIONS:____

TRIAL #:	CIRCLE PATIENT'S RESPONSE BELOW				TARGET:
1	BOEKRAK	YSKAS	GLYPLANK	POSBUS	GLYPLANK
2	VOELNES	POSBUS	KOELDRANK	REENJAS	VOELNES
3	SKILPAD	BOOMSTAM	KLEINGELD	VERFKWAS	BOOMSTAM
4	HANDSAK	VLIEGTUIG	SKILPAD	POSBUS	SKILPAD
5	YSKAS	REENBOOG	VOELNES	SONSKYN	VOELNES
6	KOELDRANK	WASBAK	SONSKYN	VERFKWAS	SONSKYN
7	SPEELGOED	POTLOOD	BLOMPOT	BOOMSTAM	SPEELGOED
8	SONBRIL	BLOMPOT	POSBUS	POTLOOD	POTLOOD
9	ROOMYS	VOORDEUR	BLOMPOT	REENBOOG	BLOMPOT
10	BOOMSTAM	ROOMYS	SPEELGOED	REENBOOG	BOOMSTAM
11	VERFKWAS	KOELDRANK	HANDSAK	LANGBROEK	KOELDRANK
12	WASBAK	KLEINGELD	VLIEGTUIG	GLYPLANK	KLEINGELD
13	VLIEGTUIG	ROOMYS	SPEELGOED	GLYPLANK	SPEELGOED
14	VOELNES	POTLOOD	REENBOOG	VERFKWAS	VERFKWAS
15	DEURKNOP	LANGBROEK	BOEKRAK	REENJAS	REENJAS
16	SONSKYN	REENJAS	SPRINGTOU	SONBRIL	SONBRIL
17	SPRINGTOU	VOELNES	VOORDEUR	WASBAK	VOORDEUR
18	ROOMYS	WASBAK	POTLOOD	SKILPAD	ROOMYS
19	HANDSAK	VOORDEUR	KOELDRANK	BOEKRAK	HANDSAK
20	SONBRIL	SPEELGOED	DEURKNOP	REENJAS	DEURKNOP
21	SONBRIL	SPRINGTOU	KLEINGELD	BOEKRAK	SONBRIL
22	YSKAS	BLOMPOT	SPRINGTOU	DEURKNOP	BLOMPOT
23	KLEINGELD	HANDSAK	YSKAS	SONSKYN	SONSKYN
24	GLYPLANK	LANGBROEK	VOORDEUR	DEURKNOP	LANGBROEK
25	LANGBROEK	BOOMSTAM	VLIEGTUIG	SKILPAD	VLIEGTUIG

Appendix H4: CRISP response form – List 4 (Afrikaans)

CRISP SPONDEES
BOOK 1: LIST 4 (TRACK #5)
PATIENT:______________________________ DATE:__________
TEST CONDITIONS:____

TRIAL #:	CIRCLE PATIENT'S RESPONSE BELOW				TARGET:
1	BOEKRAK	YSKAS	GLYPLANK	POSBUS	YSKAS
2	VOELNES	POSBUS	KOELDRANK	REENJAS	KOELDRANK
3	SKILPAD	BOOMSTAM	KLEINGELD	VERFKWAS	VERFKWAS
4	HANDSAK	VLIEGTUIG	SKILPAD	POSBUS	POSBUS
5	YSKAS	REENBOOG	VOELNES	SONSKYN	YSKAS
6	KOELDRANK	WASBAK	SONSKYN	VERFKWAS	SONSKYN
7	SPEELGOED	POTLOOD	BLOMPOT	BOOMSTAM	BLOMPOT
8	SONBRIL	BLOMPOT	POSBUS	POTLOOD	POTLOOD
9	ROOMYS	VOORDEUR	BLOMPOT	REENBOOG	BLOMPOT
10	BOOMSTAM	ROOMYS	SPEELGOED	REENBOOG	BOOMSTAM
11	VERFKWAS	KOELDRANK	HANDSAK	LANGBROEK	HANDSAK
12	WASBAK	KLEINGELD	VLIEGTUIG	GLYPLANK	GLYPLANK
13	VLIEGTUIG	ROOMYS	SPEELGOED	GLYPLANK	GLYPLANK
14	VOELNES	POTLOOD	REENBOOG	VERFKWAS	VOELNES
15	DEURKNOP	LANGBROEK	BOEKRAK	REENJAS	REENJAS
16	SONSKYN	REENJAS	SPRINGTOU	SONBRIL	REENJAS
17	SPRINGTOU	VOELNES	VOORDEUR	WASBAK	SPRINGTOU
18	ROOMYS	WASBAK	POTLOOD	SKILPAD	ROOMYS
19	HANDSAK	VOORDEUR	KOELDRANK	BOEKRAK	BOEKRAK
20	SONBRIL	SPEELGOED	DEURKNOP	REENJAS	DEURKNOP
21	SONBRIL	SPRINGTOU	KLEINGELD	BOEKRAK	BOEKRAK
22	YSKAS	BLOMPOT	SPRINGTOU	DEURKNOP	YSKAS
23	KLEINGELD	HANDSAK	YSKAS	SONSKYN	YSKAS
24	GLYPLANK	LANGBROEK	VOORDEUR	DEURKNOP	DEURKNOP
25	LANGBROEK	BOOMSTAM	VLIEGTUIG	SKILPAD	LANGBROEK

Appendix H5: CRISP response form – List 5 (Afrikaans)

CRISP SPONDEES
BOOK 1: LIST 5 (TRACK #6)
PATIENT:_________________________________ **DATE:**__________
TEST CONDITIONS:____

TRIAL #:	CIRCLE PATIENT'S RESPONSE BELOW				TARGET:
1	BOEKRAK	YSKAS	GLYPLANK	POSBUS	YSKAS
2	VOELNES	POSBUS	KOELDRANK	REENJAS	VOELNES
3	SKILPAD	BOOMSTAM	KLEINGELD	VERFKWAS	VERFKWAS
4	HANDSAK	VLIEGTUIG	SKILPAD	POSBUS	HANDSAK
5	YSKAS	REENBOOG	VOELNES	SONSKYN	YSKAS
6	KOELDRANK	WASBAK	SONSKYN	VERFKWAS	KOELDRANK
7	SPEELGOED	POTLOOD	BLOMPOT	BOOMSTAM	BOOMSTAM
8	SONBRIL	BLOMPOT	POSBUS	POTLOOD	POSBUS
9	ROOMYS	VOORDEUR	BLOMPOT	REENBOOG	VOORDEUR
10	BOOMSTAM	ROOMYS	SPEELGOED	REENBOOG	ROOMYS
11	VERFKWAS	KOELDRANK	HANDSAK	LANGBROEK	HANDSAK
12	WASBAK	KLEINGELD	VLIEGTUIG	GLYPLANK	VLIEGTUIG
13	VLIEGTUIG	ROOMYS	SPEELGOED	GLYPLANK	ROOMYS
14	VOELNES	POTLOOD	REENBOOG	VERFKWAS	REENBOOG
15	DEURKNOP	LANGBROEK	BOEKRAK	REENJAS	BOEKRAK
16	SONSKYN	REENJAS	SPRINGTOU	SONBRIL	SONSKYN
17	SPRINGTOU	VOELNES	VOORDEUR	WASBAK	SPRINGTOU
18	ROOMYS	WASBAK	POTLOOD	SKILPAD	WASBAK
19	HANDSAK	VOORDEUR	KOELDRANK	BOEKRAK	BOEKRAK
20	SONBRIL	SPEELGOED	DEURKNOP	REENJAS	REENJAS
21	SONBRIL	SPRINGTOU	KLEINGELD	BOEKRAK	SONBRIL
22	YSKAS	BLOMPOT	SPRINGTOU	DEURKNOP	BLOMPOT
23	KLEINGELD	HANDSAK	YSKAS	SONSKYN	HANDSAK
24	GLYPLANK	LANGBROEK	VOORDEUR	DEURKNOP	DEURKNOP
25	LANGBROEK	BOOMSTAM	VLIEGTUIG	SKILPAD	BOOMSTAM

Appendix H6: CRISP response form – List 6 (Afrikaans)

CRISP SPONDEES
BOOK 1: LIST 6 (TRACK #7)
PATIENT:______________________ DATE:__________
TEST CONDITIONS:______________________

TRIAL #:	CIRCLE PATIENT'S RESPONSE BELOW				TARGET:
1	BOEKRAK	YSKAS	GLYPLANK	POSBUS	GLYPLANK
2	VOELNES	POSBUS	KOELDRANK	REENJAS	VOELNES
3	SKILPAD	BOOMSTAM	KLEINGELD	VERFKWAS	VERFKWAS
4	HANDSAK	VLIEGTUIG	SKILPAD	POSBUS	SKILPAD
5	YSKAS	REENBOOG	VOELNES	SONSKYN	SONSKYN
6	KOELDRANK	WASBAK	SONSKYN	VERFKWAS	WASBAK
7	SPEELGOED	POTLOOD	BLOMPOT	BOOMSTAM	BOOMSTAM
8	SONBRIL	BLOMPOT	POSBUS	POTLOOD	BLOMPOT
9	ROOMYS	VOORDEUR	BLOMPOT	REENBOOG	VOORDEUR
10	BOOMSTAM	ROOMYS	SPEELGOED	REENBOOG	SPEELGOED
11	VERFKWAS	KOELDRANK	HANDSAK	LANGBROEK	VERFKWAS
12	WASBAK	KLEINGELD	VLIEGTUIG	GLYPLANK	VLIEGTUIG
13	VLIEGTUIG	ROOMYS	SPEELGOED	GLYPLANK	SPEELGOED
14	VOELNES	POTLOOD	REENBOOG	VERFKWAS	VOELNES
15	DEURKNOP	LANGBROEK	BOEKRAK	REENJAS	LANGBROEK
16	SONSKYN	REENJAS	SPRINGTOU	SONBRIL	REENJAS
17	SPRINGTOU	VOELNES	VOORDEUR	WASBAK	SPRINGTOU
18	ROOMYS	WASBAK	POTLOOD	SKILPAD	SKILPAD
19	HANDSAK	VOORDEUR	KOELDRANK	BOEKRAK	HANDSAK
20	SONBRIL	SPEELGOED	DEURKNOP	REENJAS	SPEELGOED
21	SONBRIL	SPRINGTOU	KLEINGELD	BOEKRAK	KLEINGELD
22	YSKAS	BLOMPOT	SPRINGTOU	DEURKNOP	DEURKNOP
23	KLEINGELD	HANDSAK	YSKAS	SONSKYN	SONSKYN
24	GLYPLANK	LANGBROEK	VOORDEUR	DEURKNOP	DEURKNOP
25	LANGBROEK	BOOMSTAM	VLIEGTUIG	SKILPAD	VLIEGTUIG

Appendix H7: CRISP response form – List 7 (Afrikaans)

CRISP SPONDEES
BOOK 1: LIST 7 (TRACK #8)
PATIENT:______________________________ **DATE:**__________
TEST CONDITIONS:______________________________

TRIAL #:	CIRCLE PATIENT'S RESPONSE BELOW				TARGET:
1	BOEKRAK	YSKAS	GLYPLANK	POSBUS	GLYPLANK
2	VOELNES	POSBUS	KOELDRANK	REENJAS	REENJAS
3	SKILPAD	BOOMSTAM	KLEINGELD	VERFKWAS	KLEINGELD
4	HANDSAK	VLIEGTUIG	SKILPAD	POSBUS	SKILPAD
5	YSKAS	REENBOOG	VOELNES	SONSKYN	SONSKYN
6	KOELDRANK	WASBAK	SONSKYN	VERFKWAS	SONSKYN
7	SPEELGOED	POTLOOD	BLOMPOT	BOOMSTAM	POTLOOD
8	SONBRIL	BLOMPOT	POSBUS	POTLOOD	POTLOOD
9	ROOMYS	VOORDEUR	BLOMPOT	REENBOOG	ROOMYS
10	BOOMSTAM	ROOMYS	SPEELGOED	REENBOOG	SPEELGOED
11	VERFKWAS	KOELDRANK	HANDSAK	LANGBROEK	KOELDRANK
12	WASBAK	KLEINGELD	VLIEGTUIG	GLYPLANK	KLEINGELD
13	VLIEGTUIG	ROOMYS	SPEELGOED	GLYPLANK	GLYPLANK
14	VOELNES	POTLOOD	REENBOOG	VERFKWAS	VERFKWAS
15	DEURKNOP	LANGBROEK	BOEKRAK	REENJAS	BOEKRAK
16	SONSKYN	REENJAS	SPRINGTOU	SONBRIL	SPRINGTOU
17	SPRINGTOU	VOELNES	VOORDEUR	WASBAK	VOELNES
18	ROOMYS	WASBAK	POTLOOD	SKILPAD	WASBAK
19	HANDSAK	VOORDEUR	KOELDRANK	BOEKRAK	HANDSAK
20	SONBRIL	SPEELGOED	DEURKNOP	REENJAS	SPEELGOED
21	SONBRIL	SPRINGTOU	KLEINGELD	BOEKRAK	KLEINGELD
22	YSKAS	BLOMPOT	SPRINGTOU	DEURKNOP	SPRINGTOU
23	KLEINGELD	HANDSAK	YSKAS	SONSKYN	SONSKYN
24	GLYPLANK	LANGBROEK	VOORDEUR	DEURKNOP	VOORDEUR
25	LANGBROEK	BOOMSTAM	VLIEGTUIG	SKILPAD	LANGBROEK

Appendix H8: CRISP response form – List 8 (Afrikaans)

CRISP SPONDEES
BOOK 1: LIST 8 (TRACK #9)
PATIENT:____________________________ **DATE:**__________
TEST CONDITIONS:__________________________________

TRIAL #:	CIRCLE PATIENT'S RESPONSE BELOW				TARGET:
1	BOEKRAK	YSKAS	GLYPLANK	POSBUS	POSBUS
2	VOELNES	POSBUS	KOELDRANK	REENJAS	REENJAS
3	SKILPAD	BOOMSTAM	KLEINGELD	VERFKWAS	SKILPAD
4	HANDSAK	VLIEGTUIG	SKILPAD	POSBUS	VLIEGTUIG
5	YSKAS	REENBOOG	VOELNES	SONSKYN	VOELNES
6	KOELDRANK	WASBAK	SONSKYN	VERFKWAS	VERFKWAS
7	SPEELGOED	POTLOOD	BLOMPOT	BOOMSTAM	BLOMPOT
8	SONBRIL	BLOMPOT	POSBUS	POTLOOD	BLOMPOT
9	ROOMYS	VOORDEUR	BLOMPOT	REENBOOG	REENBOOG
10	BOOMSTAM	ROOMYS	SPEELGOED	REENBOOG	BOOMSTAM
11	VERFKWAS	KOELDRANK	HANDSAK	LANGBROEK	LANGBROEK
12	WASBAK	KLEINGELD	VLIEGTUIG	GLYPLANK	KLEINGELD
13	VLIEGTUIG	ROOMYS	SPEELGOED	GLYPLANK	SPEELGOED
14	VOELNES	POTLOOD	REENBOOG	VERFKWAS	VERFKWAS
15	DEURKNOP	LANGBROEK	BOEKRAK	REENJAS	DEURKNOP
16	SONSKYN	REENJAS	SPRINGTOU	SONBRIL	SPRINGTOU
17	SPRINGTOU	VOELNES	VOORDEUR	WASBAK	VOORDEUR
18	ROOMYS	WASBAK	POTLOOD	SKILPAD	POTLOOD
19	HANDSAK	VOORDEUR	KOELDRANK	BOEKRAK	HANDSAK
20	SONBRIL	SPEELGOED	DEURKNOP	REENJAS	SPEELGOED
21	SONBRIL	SPRINGTOU	KLEINGELD	BOEKRAK	KLEINGELD
22	YSKAS	BLOMPOT	SPRINGTOU	DEURKNOP	BLOMPOT
23	KLEINGELD	HANDSAK	YSKAS	SONSKYN	KLEINGELD
24	GLYPLANK	LANGBROEK	VOORDEUR	DEURKNOP	LANGBROEK

Appendix I: Aided responses of participants

Participant	Pre-implant thresholds:						Thresholds with CI 1:						Thresholds with CI 2:						*SPC
No.	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	PTA	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	PTA	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	PTA	CI 1
1	25	35	40	55	80	43	22	22	22	16	22	20	24	26	22	20	24	23	7
2	-	45	45	55	75	48	30	30	20	24	26	25	30	28	20	26	28	25	7
3	Information not available						24	28	32	30	30	30	28	32	30	26	34	29	7
4	Information not available						26	30	24	26	28	27	24	32	28	30	30	30	7
5	40	50	50	50	65	50	26	24	24	24	26	24	34	36	36	34	40	35	7
6	70	60	75	75	>85	70	28	32	24	24	38	27	28	30	28	22	28	27	7
7	Information not available						30	32	32	26	30	30	30	32	30	32	32	31	7
8	-	75	85	85	85	83	28	26	24	18	22	23	26	26	20	18	22	21	7
9	50	60	70	90	90	73	32	36	32	30	36	33	28	34	32	30	34	32	7
10	30	40	45	55	65	47	26	36	36	32	34	35	28	34	36	32	34	34	7

*** SPC (Speech perception category) 7:** 51-100% for open-set word recognition of words and sentences (Clark, Cowan & Dowell, 1997)